THE OHIO STATE UNIVERSITY

RESEARCH FOUNDATION

1314 KINNEAR ROAD COLUMBUS, OHIO 43212

Report 1701-Final-2

TASERSIAQ AREA-SUKKERTOPPEN ICE CAP STUDIES

R. P. Goldthwait
Institute of Polar Studies

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R E P O R T

By

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For the period: 1 September 1963 - 1 April 1964

Submitted by: R. P. Goldthwait

Institute of Polar Studies

Date: April 1964

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INTRODUCTION

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ARTHUR MIRSKY

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METEOROLOGICAL OBSERVATIONS IN THE TASERSIAQ AREA DURING SUMMER, 1963

by

F. LOEWE

INTRODUCTION

During the summer of 1963 some meteorological observations were made in the region south of Søndre Strømfjord in western Greenland by a team from the Institute of Polar Studies at The Ohio State University. Their purpose was to study the summer climate of this interesting dry tundra region and to provide background information for work being done or planned in other branches of science such as glaciology and biology. It was intended further to check the instrumentation for more extensive work later in the field of meteorology. The recording instruments were installed and serviced and the visual observations were taken by Mr. Henry Brecher and Mr. Adolph Kryger; the observations cover the months of July and August. July is the warmest month and August the third warmest month in this region, according to a summary of the weather and climate of Sondrestrom Air Base prepared by Detachment 47, 12th Weather Squadron, in 1962.

The observations were taken at the base for the summer operations ("Base") (66°16'N, 51°13'W) near the south shore of a big lake (Tasersiaq), and at the snout of the easternmost glacier descending from the Sukkertoppen Ice Cap ("Glacier") (66°15'N, 51°14'W). The time used for the observations was the mean time for 45°W which is 26 to 30 minutes ahead of true local time. The height of the Base is about 15 m above the level of Tasersiaq, which is at 670 m according to the map (Camp Lloyd sheet, Greenland; scale 1:250,000; Army Map Service, Corps of Engineers). The Base lies on a level terrace near the western end of Tasersiaq. The wide lake-filled valley is flanked on the northern side by a range slightly more than 1000 m high, and on the southern side by hills which reach 1200 m and behind which the Sukkertoppen Ice Cap is situated. In summer the mountains are almost completely free of snow. To the east extends Tasersiaq, south of which lie two local ice caps; the continental ice sheet lies far to the east. The outlet of the lake to the west is closed by mountains broken only by the narrow winding Sarfartoq gorge.

The Glacier station lies on a moraine just north of the end of Tasersiaq Tongue (Loewe and others, 1962). Its height is approximately 360 m above the lake; 1040 m above sea level. To the west-southwest the ice of Tasersiaq Tongue is higher than the station.

In this paper, data from the Sondrestrom Air Force Base have frequently been used. It is situated on the loam terraces at the head of Søndre Strømfjord at a height of 50 m above the level of the fjord.

The meteorological shelter at the Base was equipped with the usual station instruments including a thermohygrograph. Pressure was recorded by a micro-barograph; direction and speed of the wind at the level of 1.7 m by a Lambrecht wind recorder. Global radiation was registered by a Robitzsch-type actinograph of the Belfort Instrument Co. of Baltimore. Visual observations were taken each three hours from 9 a.m. to 9 p.m. The Glacier station recorded temperature, wind, and global radiation. It was serviced weekly.

The region of western Greenland near the Arctic circle is relatively well covered by meteorological stations. Apart from the very complete observations at Sondrestrom Air Force Base, there is a station (Dye 1) on a mountain top, Qaqatoqaq, north of the mouth of Søndre Strømfjord ($66^{\circ}38$'N, $52^{\circ}52$'W, 1450 m); another on the Ice Sheet east of Søndre Strømfjord (Dye 2) (about $66\frac{1}{2}^{\circ}$N, $42\frac{1}{2}^{\circ}$W, 1900 m); and Danish meteorological stations at the outer coast.

PRESSURE

During transport by helicopter from Søndre Strømfjord to the Base, the microbarograph exceeded the available range and had to be reset. This was not completely successful. If the map height of Tasersiaq, 670 m, is correct and hence the height of the Base 685 m, it is possible to calculate with the aid of temperature observations the pressure at the Base. The result is that a correction of -0.24" of mercury (-8.3 mb) must be applied. The maximum pressure during July and August was then 946 mb, and the minimum 916 mb; the simultaneous sea level values at Sondrestrom were 1029 mb and 996 mb.

RADIATION

The bimetal actinographs provided an almost unbroken record of short-wave radiation from sun and sky upon the horizontal surface for July and August, 1963. The manufacturer supplied charts divided in cal/cm^2/min. No calibration values for different heights of the sun or for clear and overcast skies are available, although other bimetal recorders under these conditions have markedly different sensitivities (Stapf, 1938). The recorded intensity during the midday hours of cloudless days at the Glacier station is about one and one-fourth of the simultaneous radiation at the Base. It is true that radiation should increase with height, but with a height difference of only 360 m the increase should be much smaller (Steinhauser, 1939). No measurements of the elevations of the horizon at the two stations have yet been made. The horizon at the Glacier station probably is less restricted than at the Base. However, because on cloudless middays the sky radiation is a small fraction of the global radiation, the freer horizon at the Glacier station cannot explain the difference either. The absolute amount of the incoming short-wave radiation, as well as the relative amount at the two stations, remains doubtful until the instruments which have been left in Greenland are recalibrated.

INTRODUCTION

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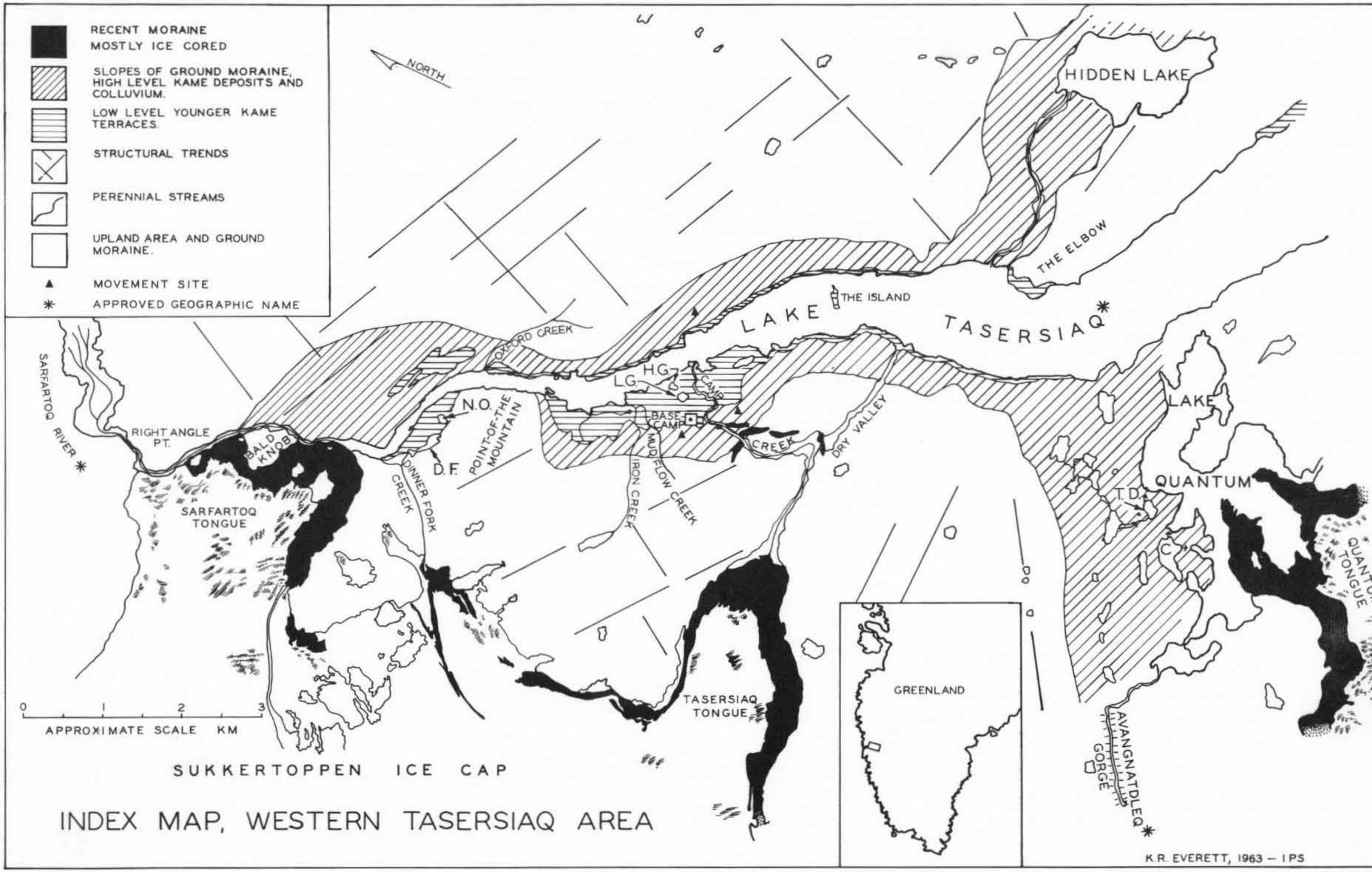

Frontispiece

Index map of the western end of Lake Tasersiaq showing important geologic features and the locations of the lakes studied. C - Caribou Lake; D.F. - Dinner Fork Lake; H.G. - High George Lake; L.G. - Low George Lake; N.O. - North Overshoe Lake; T.D. - Two Duck Lake

At the Glacier station the smooth curve of incoming radiation on cloudless days reaches its maximum only at or near 2 p.m. This is surprising, particularly as the Base records show no such shift in time. At the Glacier and at the Base, the instrument windows faced north instead of south as recommended by the manufacturer; but this cannot be the reason for the delay of the maximum. It can perhaps be explained by the fact that the neighboring glacier is higher than the actinograph, and that some solar radiation is reflected from the ice toward the instrument. The relative positions of the ice surface and the instrument are such that this might happen during early afternoon.

It is possible to compare the radiation received during clear days with that of days with a low overcast. If we suppose that the instruments are equally sensitive to direct and diffuse radiation (but this is by no means established), the proportion in the second half of August is 0.41 at the Base and 0.47 at the Glacier station. This corroborates earlier results concerning the strong transmission of solar radiation through the relatively thin clouds of high latitude (Vowinckel and Orvig, 1962).

TEMPERATURE

Table I contains the temperatures in $^{\circ}$C at three-hour intervals at the Glacier, the Base, and Sondrestrom Air Force Base for the period 3 July to 28 August 1963.

TABLE I. MEAN TEMPERATURES 3 JULY TO 28 AUGUST 1963 ($^{\circ}$C)

3-31 July	0	3	6	9	12	15	18	21	Mean	Mean Max.	Mean Min.
Glacier	1.9	1.1*	2.2	3.9	5.1	5.3**	5.1	4.1	3.8	6.8	0.4
Base	4.4	3.1*	4.3	6.8	8.7	9.2**	8.4	7.1	6.5	10.4	2.4
Sondrestrom	7.9	6.1*	7.2	10.1	12.8	13.6**	13.3	11.0	10.2	14.7	5.5
1-28 August											
Glacier	2.9	2.1*	3.1	4.9	6.4	6.6**	5.8	3.6	4.5	7.8	1.3
Base	5.4	4.2*	4.2	7.8	10.1	11.3**	9.9	6.7	7.4	11.7	3.6
Sondrestrom	7.6	5.5*	5.6	10.0	13.1	14.9**	13.7	10.2	10.1	15.3	4.3

* minimum

** maximum

Observations for the entire months of July and August are available for the Base and Sondrestrom. The mean monthly temperatures in July are 6.4 and 10.2, and in August are 6.9 and 9.6. The Glacier data have been taken from the thermograph which was checked weekly by a sling thermometer at the time the chart was changed. At the Base the temperatures from 9 through 21 hours were taken from the readings of the dry bulb thermometer; the data for 0, 3, and 6 hours are from the thermograph record. At the Base the mean monthly temperatures from the dry bulb readings and from the thermograph for the period 9 through 21 hours correspond reasonably well. This does not, however, apply to the individual hours. The thermograph reads consistently lower than the thermometer during the time of rising temperature and higher during the period of falling temperature. For the hours of 9 and 21 the difference is of the order of 0.4-0.5°C. This discrepancy can have two causes. The drum of the thermograph is approximately half an hour ahead of actual standard time, but this is an unlikely explanation as the charts have been put on and taken off at correct times. The other, more likely, explanation is a marked inertia of the thermograph. If this reason is accepted, the temperature difference between Sondrestrom and Base would be too small at midnight when the temperature is still falling. Furthermore, if the same lag does not apply to the recording instrument at the Glacier station, which is of another type, the temperature difference at midnight between Base and Glacier will be too great.

If the temperatures of Table I are taken at their face value, the daily variation derived from the three-hour data is larger ($8\frac{1}{2}^{\circ}$) at the lowest elevation (i.e., Sondrestrom) than at the Base ($6\frac{1}{2}^{\circ}$) and Glacier (4°). The mean aperiodical daily ranges are larger at the three stations -- 10°, 9°, and 7°.

The absolute extreme temperatures at the three stations between 3 July and 28 August are given in Table II.

TABLE II. EXTREME TEMPERATURES 3 JULY TO 28 AUGUST (°C)

	Sondrestrom	Base	Glacier
Abs. Max.	21	17	13
Abs. Min.	0	-2	-5

As expected the maximum temperature decreases with height more strongly than the minimum temperature. This is shown by the absolute extremes of Table II as well as by the mean extremes of Table I. The mean maximum for July and August is 8° colder at the Glacier than near sea level; the mean minimum only 4°.

The extremes of Table I at Base and Glacier are taken from the thermograph records. Readings from a minimum thermometer in the shelter at the Base are available from 10 July to 31 August. These are, on the average, 0.7°C lower than the recorded minima of the thermograph. This suggests that the minimum temperatures of Table I at the Base are too high. They had to be retained because for both extremes at the Glacier and for the maxima at the Base only the thermograph traces are available. On the average the maximum temperature at the Base occurs shortly after 15 hours and the minimum at 3 hours; at Sondrestrom the times of the extremes are 15 hours and 4 hours.

The vertical temperature lapse rates can be calculated from the simultaneous temperatures at the different stations. They are given in Table III.

TABLE III. TEMPERATURE LAPSE RATES, IN °C/100 m, JULY-AUGUST, 1963

		0	3	6	9	12	15	18	21	Mean
Sondrestrom - Base	630 m	.44	.35*	.35*	.42	.58	.66	.70**	.62	.51
Base - Glacier	360 m	.71	.59	.44*	.84	1.03	1.24**	1.10	.73	.82
Sondrestrom - Glacier	990 m	.53	.43	.38*	.56	.73	.85**	.83	.65	.61

* minimum
** maximum

The mean lapse rate between sea level and Base has a normal value. The lapse rate between Base and the Glacier is much larger. Big lapse rates are typical for mountain regions at a time when the temperature at the upper station is kept low because part of the incoming heat is used for the melting of ice and snow.

The temperature lapse rates have a very marked daily variation. In the morning they are only half as big, or less, as in the afternoon. In the afternoon the lapse rate between Base and Glacier exceeds the adiabatic one. This is typical for the katabatic wind that flows down from the ice cap.

A study also was made to determine whether the lapse rates for clear and overcast days are significantly different. The results for six clear, or almost clear, and five very cloudy days are given in Table IV. As is generally the case in high latitudes, the mean lapse rates of temperature are smaller on clear than on overcast days. Because of the formation of ground inversions with a clear sky the lapse rate is particularly small in the morning. On the other hand, on sunny days, because of solar heating at the lower level, the lapse rate in the afternoon is bigger than on overcast days. It is remarkable that even with an overcast sky the lapse rates in the afternoon remain superadiabatic between the Base and Glacier.

TABLE IV. TEMPERATURE LAPSE RATES ON CLEAR AND OVERCAST DAYS ($^{o}C/100$ m)

		0	3	6	9	12	15	18	21	Mean
Clear Days	Sondrestrom - Base	.34	.26*	.30	.47	.60	.64**	.64**	.51	.47
	Base-Glacier	.62	.62	.46*	.93	1.00	1.47**	1.17	1.09	.86
	Sondrestrom - Glacier	.44	.39	.36*	.64	.75	.95**	.83	.72	.61
Over-cast Days	Sondrestrom - Base	.43	.39*	.43	.51	.51	.60	.60	.64**	.56
	Base-Glacier	.79	.79	.63*	.79	1.10	1.18	1.26**	1.10	.95
	Sondrestrom - Glacier	.55	.53	.50*	.61	.72	.81	.83**	.81	.69

* minimum
** maximum

From the pressure difference between the stations and the known difference of their heights, the mean virtual temperature between the stations can be calculated. The change in the pressure difference during the day allows us to determine the diurnal variation of the mean temperature between the stations. Neglecting the doubts concerning the height difference between the stations and, more importantly, those doubts regarding the diurnal temperature variation, and assuming the absence of a mean horizontal pressure gradient, Table V gives the diurnal variation of the free air temperature between Sondrestrom and Base.

TABLE V. DIURNAL VARIATION OF TEMPERATURE, IN DEVIATIONS FROM AVERAGE TEMPERATURE (^{o}C)

	0	6	12	18
Sondrestrom - Base	-0.6	-0.9*	0.2	0.9**
Sondrestrom	-2.4	-3.7*	2.8	3.3**
Base	-2.0	-2.7*	2.4**	2.2

* minimum **maximum

For comparison the deviations of the shelter temperatures at Sondrestrom and Base have been added from Table I. As is generally the case, the diurnal temperature variation of the air column between the two stations is much smaller than the temperature variation at the stations themselves.

HUMIDITY

Atmospheric humidity was observed only at the Base. A hair hygrograph recorded the relative humidity, and dry and wet bulb thermometers were read at 9, 12, 15, and 18, and 21 hours. The two instruments give widely differing results; the hair hygrograph seems to be at fault. Even with prolonged drizzle it records relative humidities of only slightly more than 70 per cent. As for the temperature observations during the daytime, the visual observations of the dry and wet thermometers were accepted. From these and the simultaneous records of the hair hygrograph, corrections were calculated which were then applied to the nighttime records of the hair hygrograph. These corrections rise from +10% for hygrograph readings of less than 20%, to +22% for hygrograph readings exceeding 45% relative humidity. Table VI gives the daily variations of the corrected relative humidity.

TABLE VI. RELATIVE HUMIDITIES, VAPOR PRESSURES, SATURATION DEFICITS, JULY - AUGUST, 1963

		0	3	6	9	12	15	18	21	Mean	Mean Max.	Mean Min
Relative Humidity	Base	80	84**	79	63	55	50*	56	67	68	91	43
	Sondrestrom	69	74**	72	60	50	47*	50	57	59		
Vapor Pressure (mb)	Base	6.8**	6.6	6.4	6.2	5.8*	5.8*	6.0	6.4	6.25		
	Sondrestrom	7.0	6.7*	6.9	7.2	7.5**	7.4*	7.6**	7.1	7.2		
Saturation Deficit (mb)	Base	1.4	1.3*	1.7	3.8	5.7	6.5**	5.3	3.3	3.6		

* minimum

** maximum

At the Base the relative humidities for July and August are very similar. By combining the wet bulb observations or the corrected relative humidities with the simultaneous observations of the temperature of the air, the vapor pressures and saturation deficits can be calculated. These calculations have been made for the 10-day means of relative humidity and temperature. This averaging introduces certain errors in the mean vapor pressure which might, however, be overlooked in view of the spread of the basic data.

The vapor pressure at the Base has one maximum at night and one minimum in the early afternoon, which correspond to the trend of the relative humidities. This variation of the vapor pressure differs from that of temperate continental regions which have generally two maxima and two minima during the day. The variation of vapor pressure at the Base is typically that of arid regions. This is interesting in view of the near-aridity of much of the Søndre Strømfjord region. The station Sondrestrom has the opposite, oceanic, type of the daily variation of vapor pressure with a maximum during the warmer part of the day. There is a weak indication of the continental afternoon minimum.

The saturation deficit which, together with the wind, determines the potential evaporation, shows a strong diurnal variation.

CLOUDINESS

Observations of the clouds have been taken at the Base between 9 and 21 hours. For the same period the differences between the cloudiness at Sondrestrom and at the Base have been determined; and by the use of these differences and the observations at 0, 3, and 6 hours at Sondrestrom, likely values of the night cloudiness at the Base have been calculated. The uncertainty of this procedure which gives the bracketed values of Table VII needs not be stressed.

TABLE VII. CLOUDINESS AT BASE (IN TENTHS), JULY AND AUGUST

	0	3	6	9	12	15	18	21	Mean
All clouds	(5.3)*	(5.7)	(6.1)	6.0	6.0	6.0	6.4**	5.8	6.1
Lowest clouds	(4.4)	(4.3)	(4.1)*	4.4	4.9	5.0**	4.6	4.6	4.7

* minimum
** maximum

There is an indication of the continental afternoon maximum of cloudiness. This maximum is better developed with the lowest clouds which are frequently the result of heating of the ground and convection.

PRECIPITATION

During July and August the rain gauge at the Base collected 41 mm of rain. The same amount was received at Sondrestrom, where it is close to the average of these two months. There were 25 days with precipitation at the Base, 18 with measurable precipitation; and 31 days at Sondrestrom, of which 18 also had measurable precipitation. At Sondrestrom the mean is 16. Altogether, the two months seem to have been nearly normal. In the last days of August some snow fell at the Base and once even at Sondrestrom. This too is normal. There is, however, a most surprising fact in the distribution of rainfall occurrences.

The heaviest fall during the two months at the Base, 14 mm, occurred on 6 July when a weak depression passed, with heavy winds at both the Base and Sondrestrom. But at Sondrestrom, only 55 miles from the Base, no rain fell at all. Conversely, the heaviest rainfall at Sondrestrom, 14 mm, fell on 22 August, and none occurred at the Base. It is quite remarkable that the conditions for rainfall can be so different over a relatively short distance, particularly since localized thunderstorms and orographically determined precipitation can be excluded. The existing weather maps give no explanation.

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GLACIAL GEOLOGY OF THE WESTERN TASERSIAQ AREA, SOUTHWEST GREENLAND

by

GEORGE CROWL and RICHARD P. GOLDTHWAIT

INTRODUCTION

Lake Tasersiaq lies in the broad deglaciated strip of land along the west coast of Greenland a little north of 66° N latitude (Frontispiece). The prominent deep valleys of the region trend east-west and northeast-southwest at a high angle to the coast, as typified by Søndre Strømfjord, 145 km long, to the north. Lake Tasersiaq occupies a complex structural valley in gneisses with minor amounts of schist and younger granites and basalt dikes. The lower portion of this lake, 11 miles long, trends northwest-southeast. The main portion of the lake trends east-west and is about 50 km long; the north-east hooked end of the lake is a large bay in another structural depression and the Greenland Ice Sheet forms part of its shore. The middle portion of the lake lies in a narrow U-shaped valley; the western portion is wider where it flanks the Avangnardleq lowland and terrace deposits and gentle mountain slopes bordering this extreme northwest tip of the lake.

On the highlands west of Lake Tasersiaq is Sukkertoppen Ice Cap, about 1800 square km in area, with a maximum elevation of 1725 m. South of the lake is another ice cap, here called the Avangnardleq Ice Cap. It is about the same size and perhaps the same elevation as Sukkertoppen, and is separated from it by the Avangnardleq lowland at the head of Evighedsfjord. Available maps indicate that it is almost isolated from the Greenland Ice Sheet and is not fed by the latter although it is contiguous. There are other small ice caps in the region.

All of the region about Sukkertoppen was glaciated during the Pleistocene; the most recent extensive glaciation is Wisconsin and no effects of still earlier glaciation can be identified. Erratics are scattered over the high slopes and uplands, grooves and striae are found in protected spots under boulders or where soil is removed. These latter indicate that the ice sheet moved westward, ranging from southwest to northwest, and was strongly guided at its base by the rugged topography adjacent to the lake.

The area was deglaciated at the close of the Wisconsin. It is probable that Sukkertoppen and its neighboring ice caps survived general deglaciation; since then they have had an existence independent of the ice sheet and probably have reacted more immediately to climatic fluctuations than the ice sheet.

The evidences of fluctuation, particularly those of the "Little Ice Age," are the principal subjects of this paper.

WISCONSIN DEPOSITS

The mountain slopes and the uplands far above Lake Tasersiaq are nearly devoid of drift. Big boulders of gneisses and granite differing from the rock of the underlying ledges are common. Small, thin, scattered deposits of till and glaciofluvial materials are found at elevations up to nearly 240 m above the lake. Thick deposits of till are usually restricted to a narrow band at the base of the mountain slopes. Only in the Avangnardleq lowland, the connecting link between Tasersiaq and Avangnardleq valleys, and on adjacent mountain slopes to the southwest is there an extensive but thin deposit of sandy till.

Kames and kame terraces border both sides of the northwest portion of the lake and are most extensive northwest of Camp Creek (Frontispiece).

Thick bodies of till and outwash are permanently frozen and thaw to a depth of less than one meter. Continuous permafrost indicates a mean annual temperature below - 2°C.

Till

Till of the Tasersiaq area is coarse, bouldery, sandy, and is derived from the local gneissic and granitic bedrock. There is sufficient clay- and silt-size material to make it relatively impermeable. The till is subject to solifluction even on low slopes because drainage is prohibited by the ubiquitous permafrost. Thus most minor depositional features have either been strongly modified or destroyed.

Glaciofluvial Deposits

Two series of kame deposits are present in the Lake Tasersiaq area: (1) high level kames on the valley slopes and adjacent upland, and (2) a series of kames and kame terraces in the wide northwest portion of the valley of Lake Tasersiaq.

High-Level Kames. --A number of high-level kames occur on the mountain slope at various elevations up to 240 m above the valley floor between Camp Creek and Point of the Mountain (Frontispiece). These are small bench deposits, generally poorly sorted and poorly stratified. Some are difficult to distinguish from till deposits, and the principal criterion for doing so in these cases is the degree of sorting of the materials.

A few moulin kames are present in Dry Valley below the "elbow" of Camp Creek; and a kame on the upland to the southeast shows a good depositional slope and decrease in pebble size from the ice contact slope toward the upland slope.

Moulin kames and narrow kame terraces are present also in the upland basin west and northwest of Hidden Lake.

Lake Tasersiaq Kames.--The floor of Lake Tasersiaq valley is covered by a variety of flat-topped kames. Kame terraces on the northeast side of the lake occupy a narrow zone between the lake shore and the till slope at the foot of the mountain wall. A few form low ridges approximately parallel to the trend of the valley. The upper surfaces of these terraces slope irregularly northwest toward the outlet of the lake from a fine terrace 13.5 m above the lake at the Elbow and from terraces at 16.5 m opposite Point of the Mountain.

Kame terrace and deltaic deposits are best displayed on the southwest side of the valley from the vicinity of Camp Creek to Point of the Mountain. Sorted, bedded glaciofluvial deposits cover most of this widest portion of the valley floor. There is an isolated narrow area of kame terraces about a mile southeast of Camp Creek.

The terraces decrease in elevation in step-like fashion from Camp Creek northwest to Point of the Mountain. The Camp Terrace is about 21 m above the lake at its southeast end and decreases by steps to 19 m, 16 m, and on down to about 6 m above lake level. This plain blocks drainage from the mountain slope so that streams occupy a series of shallow marshy depressions between the slope and the gravel plain. They join streams tributary to Lake Tasersiaq which usually cross the plain at the margins of the terrace "steps."

This stepped plain is pitted with a few large kettle ponds. The largest of these depressions is breached by Camp Creek and is partially filled by its alluvial fan spread into the kettle hole at the base of the mountain.

The surface of the terraces is generally covered with desert pavement of pebbles 5 to 50 mm in diameter. In some areas numerous pebbles to 300 mm diameter are fitted like riprap. Wind action has concentrated at the surface pebbles originally scattered through the sand as well as lenticular deposits of pebbles.

Pebble counts on kame terraces at various places along Tasersiaq valley show a wide and non-systematic variation in lithologies within individual terraces and from one terrace to another.

Sections of kame terraces show no systematic variation in grain size along the lake. The Camp Creek terrace system does show reasonably consistent internal variation in grain size. Within the Camp Creek terrace system, however, grain size tends to decrease irregularly away from the lake and to some extent northwest toward the outlet; this indicates a source of sediments in an ice tongue in the site of Lake Tasersiaq, and that sediments spread laterally from that source.

Similar, higher sloping terrace systems were noted in reconnaissance on the north side of the lake 3 to 16 km east of the Elbow.

WISCONSIN DEGLACIATION

The Tasersiaq area was presumably deglaciated at the close of the Wisconsin, about 9000 years ago, as dated much further north in West Greenland. The absence of end moraines fitting a continental ice margin, and the pattern of hillside kames within the area and on the upland between Tasersiaq and Søndre Strømfjord, indicate that the ice stagnated and melted down in some places. Thus kames were deposited at a number of places on the mountain slopes and uplands wherever ponds might form between rock and ice walls.

It was not until the late-melting ice tongue retreated to the present position of Lake Tasersiaq that systematic development of kame terraces began. The series of kame terraces on the northeast side of the lake, decreasing in elevation northwestward, indicates a succession of ponds in the drainage line. It cannot be proved that they were built simultaneously. The extensive development of kame terraces in the wide portion of the valley owes its origin to an ice dam at Point of the Mountain, creating a lake in the lowland.

POST-WISCONSIN GLACIATIONS

Present Day Glaciation

Sukkertoppen Ice Cap accumulates snow on an undulating highland surface above 1370 m (Bull, 1962) and drains by numerous tongues on all sides of the cap. Three of these tongues are within the area of investigation. They are, in order from northwest to southeast: (1) the Sarfartoq Tongue down to Sarfartoq River level at an elevation of 610 m near the outlet of Lake Tasersiaq, (2) Tasersiaq Tongue on Camp Creek to 1050 m, and (3) Twin Tongue above Moraine Lake in the Avangnardleq lowland.

The Avangnardleq Ice Cap southeast of Sukkertoppen drains by numerous tongues into Avangnardleq gorge and by one tongue into Moraine Lake. This is the only tongue of this ice cap that has been investigated.

At the present time, each of the ice tongues in the area is well within the border of prominent ice-cored end moraines. Apparently the ice margins are retreating, but the rate is unknown. The Sarfartoq Tongue is still building its end moraine but has retreated as much as 300 m from the outer crest of this moraine. Tasersiaq Tongue is within its latest end moraine and is not building another moraine at the present time. Twin Tongue of Sukkertoppen Ice Cap has retreated the greatest distance from its end moraine. This is readily accounted for by the steep mountain slope just below the ice front where wastage has been rapid, and the mountain slope between the ice edge and the end moraine at the base is essentially barren of drift.

The Moraine Lake Tongue of the Avangnardleq Ice Cap built a prominent moraine in the Moraine Lake and has also retreated about half a mile from its farthest end moraine.

Parts of the lateral moraines of the Sarfartoq Tongue and Tasersiaq Tongue are ice-cored even well beyond the present ice margin. At the outer, north, edge of Tasersiaq moraine a long high wall of ice stands in shadow below the covering moraine.

Little Ice Age Advance

Several lines of evidence indicate a period of glacier expansion that may have begun several hundred years ago and ended in the past century -- sometimes called the "Little Ice Age." The ice-cored end moraines on all the glacier tongues visited indicate ice front retreat from such a recent advance. The mountain slopes on the northwest margin of the Sarfartoq tongue show a "trim line" 35 m above the ice surface. Below this trim line the rock is fresh and clean; above it the rock is covered with extensive growth of lichens, and is deeply etched by weathering. This trim line indicates that very recently the Sarfartoq tongue was at least 35 m thicker than at present. This greater thickness of the tongue is readily correlated with the position of the end moraines well beyond the present margin of the ice.

Three tongues of Sukkertoppen Ice Cap have prominent lateral moraines at their margins and prominent end moraines beyond the present ends of the tongues. Only the tongue down Dinner Fork Creek lacks a prominent moraine because of its small size. These moraines are composed of fresh, gray, coarse, bouldery till, and all are ice-cored. As one climbs any slope the pieces are unstable. Plant growth is rare on any of these moraines--a few willows (Salix spp) and poppies (Papava radicatum), and still fewer small lichens are the principal plants. The ice cores in the moraines and the paucity of plant growth indicate that they are still unstable. This suggests in turn that the climax of glaciation was only about a century ago.

The Sarfartoq Tongue divides into two lobes around a prominent outcrop, Bald Knob, next to Sarfartoq River gorge. The downstream lobe borders the river in an ice cliff undermined by the river. Lichen-free rock on the northeast side of the river indicates that this lobe extended about 150 m across the river and formed a dam there, ponding the water of Lake Tasersiaq 10 m above the present level. The fresh moraine indicating farthest advance of the ice wraps around the Bald Knob like a mantle and stretches from near the crest of the knob down to the river. Thus the lower southeastern part of the moraine was built into ponded water.

Lateral moraines border Tasersiaq Tongue and rise to a sharp crest 10 to 20 m above the ice. The end moraine extends about 300 m beyond the ice front. The lateral moraine is ice-cored beyond the present limits of the ice, and even shows as a shear ice slope along the outer, northern margin of the loop. This is interpreted to indicate a recent retreat of the ice front to its present position. As with other tongues of this ice cap studied earlier by others (Weidick, 1963), this implies a previous advance to the outermost fresh moraine.

Twin Tongue of Sukkertoppen Ice Cap shows the most spectacular retreat of any of these three lobes. Retreat is accentuated by the steep mountain slope immediately in front of the ice. The terminal moraine of Little Ice Age advance has dammed a melt-water lake at the base of the mountain and has also dammed some drainage lines beyond the margin to form lakes fed by normal run-off and ground water percolation.

One tongue of Avangnardleq Ice Cap drains into Moraine Lake and has built prominent loop moraines in the lake. At the time of greatest ice advance, when the moraines were formed in the lake, the ice front reached the rock wall north of the tongue and blocked drainage in the side valley above this point. A small proglacial lake formed here, dammed by the ice itself. A striking trim line marking the surface of the lake is about 23 m above the adjacent lateral moraine. Part of the lake still remains dammed behind the moraine, but the upper part of the lake basin is dry. Boulders are abundant on the floor of the basin. Their flat or gently sloping surfaces are covered with a thin layer of silt that has not been removed by erosion subsequent to lowering of lake level. The freshness of the trim line, and the silt cover on the boulders indicate very recent drainage of the lake, probably within the last 50 years.

Older Glaciation

Two end moraines of the Tasersiaq Tongue cross Camp Creek at about 90 and 150 m above Lake Tasersiaq (i.e., 275 and 215 m below the present ice tongue). The moraine loops point down valley and are thus clearly related to an ice tongue in the stream valley and are not related to the continental ice sheet. They are presumably of late- or Post-Pleistocene age, and indicate an ice advance here that is not recorded at any other tongues. They support a growth of herbaceous vegetation as good as that on the surrounding area, and boulders in the moraine are extensively covered with lichen. Such a cover is usually at least a thousand years old (Beschel, 1958); they are distinctly older than the current "gray" end moraines of the ice cap, and they do not fit the general deglaciation of the area by Inland Ice. They cannot now be dated more precisely but they indicate long existence of Sukkertoppen Ice Cap.

Camp Creek flows from the Tasersiaq Tongue northeast about a mile down part of a long straight depression controlled by a fracture or fault zone in the bedrock, then turns abruptly west at a moraine barrier for half a mile along the strike of the gneissic foliation, and thence northeast down the steep lower mountain slope.

The lower, older moraine of the pair loops across Camp Creek about 90 m above Tasersiaq valley floor, climbs the hill southeast, and follows the bedrock ridge bounding Camp Creek valley to the upper "elbow." Here, as noted, it extends across the structural valley as a ridge about 6 m high and 150 m wide, diverting the stream into its present course. The inner moraine of the pair is short, extending just less than one-half km on either side of the stream and dying out quickly against the steep mountain slopes.

Both end moraines are very sandy. The lower moraine has pockets of fine sand and silt, some well laminated, which indicate small, deep ponds during their deposition. How these ponds were contained is not clear, for the deposits are exposed only in a fresh stream cut and are covered elsewhere.

GLACIAL LAKE TASERSIAQ

The valley of Lake Tasersiaq was occupied until a recent date by a glacial lake dammed by the Sarfartoq Tongue of Sukkertoppen Ice Cap at the outlet gorge at the northwest end. This temporary lake drained southwest by way of Avangnardleq lowland and valley into Evighedsfjord.

An old lake shore can be traced for at least 50 km along the present lake at a height of 10 m above the low water level (the present lake fluctuates by as much as 2 m annually). It shows best as a wave cut bench 1 to 3 m wide in glacial gravels; sometimes there are double benches about 1 m apart. The higher shoreline is less continuous than the lower. The bench in gravel is continuous for many hundreds of meters and is only locally interrupted, presumably where wave action was ineffective, either because the materials were too coarse, or because the spot was sheltered from strong winds. Late-lasting lake ice may have reduced wave action locally but exerted ice shove at some places. Most stretches of the bench are characterized by the accumulation of a bouldery lag-gravel; the fine materials have been washed out.

The shoreline is intermittently developed on the till slopes in the Avangnardleq lowland and to the northwest in Tasersiaq valley. The clear evidence of solifluction on the till slopes indicates that the shore line has been destroyed at many places by sliding away. In a few places, solifluction lobes have buried the shore.

The shore can be traced at the northwest end of the lake by a color change in gravel, and in the rock-walled central portion of the lake east of the Elbow by a color change in rock denoting the division between sparse and abundant lichen growth. Above this trim line, which is coincident with the wave-cut bench in gravel, rocks are dark with lichen growth which covers 80 per cent of the surface; below it rocks are light, for lichen covers less than 30 per cent. The amount of lichen suggests that the glacial high lake stage may have ceased about a century ago.

In 1879 a missionary, Kleinschmidt, wrote in a letter that the Eskimos told him that Sarfartoq River outburst and took four big boats away. This river is blocked from time to time by a glacier branch...." Probably this is Sarfartoq Glacier and the date confirms release of the ice-dammed lake 84 or more years ago (Jensen, 1879).

The shoreline has been traced into Sarfartoq gorge on the northeast side of the lake. Its trace becomes less and less conspicuous as gravel deposits diminish, and it finally disappears opposite Bald Knob, the barrier to the Sarfartoq Tongue. It appears on the southwest side of the valley as benches in gravel within 180 m of the Sarfartoq moraine.

The outlet of higher glacial Lake Tasersiaq was by way of Avangnardleq lowland. Careful hand-levelling across the broad divide between Lake Tasersiaq and Moraine Lake demonstrates the presence of two broad, shallow passes between the lake basins at 9.8 and 10.1 m above Lake Tasersiaq. An unusually large number of boulders in the till in one of these passes is ascribed to removal of fine-grained materials by the outlet stream.

Moraine Lake drains southwest into a small lake, thence via rapids and a waterfall into Avangnardleq Gorge about 150 m wide and 120 m deep with vertical walls along the strike of the gneiss in that area. The great depth of the gorge is ascribed to accelerated erosion during the period of drainage diversion. The size of this gorge implies a long period of drainage this way, possibly all of the Little Ice Age. Now part of the walls are masked under huge talüses. These taluses must have begun to accumulate during the Little Ice Age by frost action on favorably oriented gneiss and are still growing so rapidly that they have partially blocked the stream. It is ponded in one place and flows through the talus in others.

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PRELIMINARY REPORT ON
MASS-WASTING IN THE LAKE TASERSIAQ AREA, SOUTHWEST GREENLAND

by

K. R. EVERETT

INTRODUCTION

The area of investigation, a portion of the foreland area of the Sukkertoppen Highland Ice, is bounded by latitudes 66°00' and 66°15' North and longitudes 51°00' and 51°30' West. It is in the Sukkertoppen Kommune, approximately 90 km south-southwest of Sondrestrom Air Base. The area has been visited on three previous occasions, in 1936 and 1938 by the West Greenland Expeditions of the University of Oxford, and in 1962 by the Institute of Polar Studies First Sukkertoppen Expedition.

In 1963 investigations were made in the ice-free areas (Frontispiece) from the Sarfartoq Glacier south-southeast to Lake Quantum on the southwest side of Lake Tasersiaq and from Right Angle Point to Hidden Lake on the northeast side of Lake Tasersiaq. The total area investigated is approximately 100 km^2.

The investigations and results presented here are part of a broader two-year study of the mass-wasting, patterned ground and soils of the area adjacent to the Sukkertoppen Ice Cap, southwest Greenland. This report includes the results of the 1963 summer field work. Another report will be prepared for publication after the conclusion of the 1964 field season and will consist of an elaboration on and refinement of the material presented herein.

I wish to thank Mr. Henry Brecher for his able assistance in surveying and data reduction. I am grateful to Dr. A. L. Washburn, Yale University, and Dr. Anders Rapp, Uppsala, Sweden, for their critical review of this report.

PHYSICAL GEOGRAPHY

Bedrock Geology

The bedrock geology of the area covered in this report has not been investigated in detail. Treves (1962) made a reconnaissance of the bedrock geology in the Tasersiaq valley; in the summer 1963, he made a detailed geologic study in the east half of the Tasersiaq area (in preparation). Because of the control which the bedrock exercises on the geomorphology, its general character and structure will be outlined.

The bedrock is composed of steeply to vertically dipping Precambrian (?) gneisses with variable amounts of included schist. The oldest gneiss in the Gneiss Gorge (east end of Lake Tasersiaq) is a grey, biotite or hornblende gneiss. In places it is a strongly contorted migmatite containing inclusions and schlieren of biotite schist, hornblende schist, and amphibolite (Treves, 1962). This description also applies to the rocks that make up the precipitous ridge which parallels Lake Tasersiaq on the northeast. Lake Tasersiaq represents a structural discontinuity between the grey paragneiss (Treves, 1962) and a similar grey paragneiss which makes up, at least in part, the dip-slope hills on the southwest. The grey paragneiss is extensively intruded by red granite or granite gneiss. The gneiss grades (?) across a structural depression into red granite and granite gneiss with minor inclusions of grey paragneiss. This last rock type is coincident with the more rugged topography up to the Sukkertoppen Highland Ice.

The gneisses on both sides of Lake Tasersiaq are intruded by large ultrabasic dikes of considerable lateral extent. Red feldspathic dikes are common and intrude the paragneisses on the southwest side of Lake Tasersiaq.

In many areas the original bedding is preserved and dips range between 20° and 65° to the northeast. At least one prominent set of joints characterizes extensive areas of this igneous-metamorphic complex, one set trending northeast-southwest and the other northwest-southeast. To a large degree, this joint set controls the major drainage network of the area.

Surficial Geology

Details of the surficial geology of Lake Tasersiaq area are treated by Crowl and Goldthwait (another section of this report) and will be discussed here in general terms as background. Broadly classified, the surficial deposits are: (1) ground moraine or till and end moraine, related to Wisconsin or earlier glaciation; (2) kame terraces and outwash, representative of several minor glacial advances or stillstands; and (3) recent end moraines and outwash close to and related to present glaciers.

Almost the entire ice-free area adjacent to the Sukkertoppen Highland Ice is blanketed by bouldery ground moraine and till (Frontispiece), except where it has been removed from steeper slopes by mass-wasting and running water. The slopes, particularly on the southwest side of Lake Tasersiaq, are complicated by a series of discontinuous kame terraces to 100 m or more above the present lake level. Similar terraces occur on the opposing slope, but are less well preserved and do not occur as high up on the slope, because either they were never deposited or they have been removed by solifluction subsequent to ice retreat. Many of these terraces have a thin veneer of ground moraine and display rock-rampart fronts.

At this end of Lake Tasersiaq, extensive areas of the valley bottom to an elevation of 19 m above present spring lake level, are occupied by flat-topped kame-terrace deposits. These deposits are related to a late-phase ice tongue in the Tasersiaq Valley (Crowl and Goldthwait). The deposits are horizontally bedded or display a gentle dip toward the valley margins. Most are sparsely covered with vegetation and have a wind-stripped surface of lag gravel.

Moraines and outwash associated with present-day glaciers cover only a small percentage of the ice-free area (Frontispiece). The moraines are ice-cored and topographically impressive. However, they are of little importance with respect to mass-wasting or patterned ground. Outwash associated with the present glaciers does display ground patterns.

Topography

The foreland area just east of the Sukkertoppen Highland Ice is characterized by long asymmetrical valleys bounded by precipitous escarpments on one side and dip-slope hills on the other. Most are occupied by underfit or beaded streams. Highland elevations range from about 500 m near Sondrestrom Air Force Base to about 1100 m near the Sukkertoppen Highland Ice.

The most pronounced topographic features of the area are Søndre Strømfjord and Avangnatdleq Fjord. The latter displays some of the most impressive scenery of the area, particularly on the south side where outlet glaciers of the Inland ice pass around imposing half-domed peaks. Both fjords follow the northeast-southwest joint set. Bowdoin Bay and western Lake Tasersiaq follow the northwest-southeast joint set and empty into Søndre Strømfjord. Lake Tasersiaq is approximately 60 km long. Ten km northwest of the 1963 Base Camp (Frontispiece) this lake empties through a narrow gorge, the sides of which rise vertically nearly 300 m. At this point the outlet is called the Sarfartoq River.

Repeated Pleistocene glaciations have sent tongues of ice down the major drainage lines, and the inland ice has completely covered the area at least once and probably several times. Changes wrought by the ice are not as pronounced as might be expected. The glaciers worked on a landscape with a well-established drainage pattern, a pattern most likely determined by streams, perhaps long before the Pleistocene. Glaciations have modified the landscape in detail, i.e., widened and perhaps deepened some valleys, oversteepened the escarpments, and in the lower reaches of Lake Tasersiaq have sculptured gneissic outliers into roches moutonnees. Kame depositions on the dip-slope hills to the southwest of Lake Tasersiaq have imparted a benched appearance to the slope profile and in one case, just south of the Base Camp, deposition of an end moraine has caused a 90° turn of Camp Creek and the abandonment of its former valley (Dry Valley).

The uplands appear to be little modified by glaciation. Till cover is thin or absent. These surfaces have undergone scour by a thinner, slower moving ice sheet. As far as the gross topography is concerned, the last significant ice advance was possibly 9000 years B.P. (Goldthwait, personal communication). Evidence from the area of Hidden Lake (Frontispiece) suggests that post-glacial erosion has just now cut its way through the valley fill material deposited during glaciation, and is once again working on a bedrock surface. Deepening of the bedrock valley by postglacial streams probably has not amounted to more than a few feet at most, except in large outlets such as the gorge north from Lake Tasersiaq.

Patterned ground

The terminology used here follows that proposed by Washburn (1956). The types of patterned ground and their distribution in the Tasersiaq area are governed primarily by the mechanical composition and slope of the surface deposits.

Nonsorted mud circles and polygons develop best in areas underlain by silty and clayey material, and as a consequence are almost absent in the area. Coarse surface material seems to favor the development of sorted polygons and nets, which are common on both sides of the Tasersiaq Valley.

Sorted and nonsorted polygons.--Sorted polygons (Fig. 1) are the most wide-spread and by far the best developed ground pattern in the Tasersiaq Valley. These features are abundant on slopes between 5° and 8°, southeast from Dry Valley to Lake Quantum (Frontispiece) and at scattered positions on the opposing slope.

Polygon diameters range from 2 to 5 m. The bordering blocks of rock are from a few decimeters to several meters in length, and many have their long axes inclined to the horizontal.

There is very little fine material in the borders except at depth. The central areas tend to be convex and covered with vegetation, and they may have one or several large boulders at the surface.

Large, well-defined, sorted polygons occur on kame-terrace deposits near the Sarfartoq tongue (Frontispiece). Individual polygons with diameters as much as 5 m are common; the borders are narrow, 3 to 4 cm. The surface of the terrace is a lag gravel. The polygonal outlines appear to be desiccation cracks (Fig. 2). The cracks are not discernible below 25 cm, and only the upper 1 to 3 cm contain the larger gravel fragments. The gravel fragments which outline the polygons range from 2 to 5 cm. This size fragment makes up much of the lag-gravel surface of the terrace including the central areas of the polygons. The polygons do not occur everywhere on the terrace, but are confined to several marginal areas where internal drainage is good.

There is considerable evidence that a process like Bryan's Gully Gravure is operative on the terrace. The polygonal borders gradually become filled with wind-blown silts and fine sands, in which plants become established. Once established the plants act as a trap for the wind-blown material and the polygonal borders are built up. This sequence has been found in all stages of construction and destruction. The result may be the obliteration of the polygonal outline or the creation of a polygon whose borders are composed not of coarse fragments but of fine sands, while the central area of the polygon still displays a coarse gravelly surface.

Over large areas of the younger kame terraces, northwest of Base Camp, only discontinuous raised polygonal borders exist which support grasses and *Campanula rotundifolia*, or polygons with depressed borders of fine sands, which are accentuated by the plant *Silene acaulis*.

Nonsorted polygons are not abundant in the valley. They are confined to the moister, sloping (1°-3°) margins of the younger kame-terraces, and to moist depressions between Lake Tasersiaq and Lake Quantum (Frontispiece). Diameters range from less than 1 m to as much as 4 m.

Sorted and nonsorted nets.--Well-developed sorted nets are common on south- and southeast-facing slopes on the uplands. The slopes range between 8° and 12°, and are covered with lichen-encrusted boulders. As the slope steepens, the nets become drawn out downslope, but are still well defined. The central areas, composed of a mixture of coarse and fine material, support only scattered clumps of grasses and several species of Carex. This material is found to spill over into the rock-filled depressions on the sides or over the downslope depressions. The flow or spill-over is thought to be largely a surface phenomenon, perhaps mudflow aided by rill-wash.

The central areas are slightly convex. The rocks at the margins commonly have their long axes inclined to the horizontal, and are relatively free of smaller fragments to a depth of 5-20 cm. Below this depth, finer fragments begin to fill completely the inter-fragmental space. At a depth of about 40 cm, the marginal and central areas are indistinguishable, either by color or texture.

Nonsorted nets are common on highland areas, which have a thin veneer of ground moraine. They are also common on the high-level kame-terraces.

Climate

Until the summer of 1963, no climatological program had been carried out at Lake Tasersiaq. The climate falls under the Tundra Climate group as defined by Trewartha (1954). Climatic records available from Sukkertoppen Village and from Sondrestrom Air Force Base span many years, but because these recording stations are respectively on the coast and inland near sea level, they are not useful in the area marginal to the Sukkertoppen Highland Ice.

Table I shows the maximum and minimum air temperature and relative humidity values for the period 1 July through 31 August 1963 for the base camp station in Tasersiaq Valley. A complete discussion of the climate of this area is given by Loewe elsewhere in this report.

TABLE I. MAXIMUM-MINIMUM TEMPERATURES AND RELATIVE HUMIDITY FOR THE PERIOD 1 JULY TO 31 AUGUST 1963 AT BASE CAMP, LAKE TASERSIAQ, GREENLAND

1963 Week	Temperature °C.		Relative Humidity (%)	
	Max.	Min.	Highest	Lowest
July 1 - 8	13.3	0.8	77	21
July 8 - 15	15.5	1.1	74	9
July 15 - 22	12.8	0.0	79	12
July 22 - 29	14.4	-0.6	77	14
July 29 - 5	14.4	2.2	79	14
Aug. 5 - 12	18.3	4.4	82	14
Aug 12 - 19	17.2	2.8	80	19
Aug 19 - 26	13.9	1.1	80	15
Aug 26 - 31	6.6	-1.7	76	22

The general climate of the Tasersiaq area is characterized by a cold, wet spring and fall, and a cool, dry summer, which in 1963 lasted about one month. It was during this month, 18 July to 24 August, that strong diurnal fluctuations in temperature and relative humidity occurred. Wind speeds of more than 20 mph are common. The highest velocity recorded was 42 mph. The prevailing winds are in the southeast quadrant, with the strongest winds from the south and southeast (Brecher and Kryger, 1963).

A total precipitation of 47 mm was recorded at the base camp station. Of this total, 32 mm fell between 26 June and 18 July, and 9 mm between 24 August and 1 September; no precipitation was recorded from 19 July to 2 August. Snow flurries occurred in all months.

Judging from snowbank accumulation, winter snowfall appears to be moderate to light. Strong southerly winds form large drifts on the northeast-facing slopes. Many of these drifts persist throughout the summer. These same strong winds keep the terraces swept clear of snow.

MASS-WASTING

Introduction

The results of mass-wasting are observed everywhere in the Tasersiaq area. Climatically the region is semi-arid. Just as in other arid or semi-arid regions, water and gravity are the prime movers in mass-wasting. Summer precipitation is slight; however, large snowbanks, some of which are perennial, provide large and long-lasting sources of water. Judging by the large areas where no lichen cover exists, snow banks of the past were considerably more extensive than at present. Many of the mass-wasting features suggest that large quantities of water were involved in their formation.

Solifluction

On the slopes surrounding Lake Tasersiaq solifluction manifests itself in the form of sheets and lobes. Whether a sheet or lobe is produced is dependent on the configuration of the bedrock, i.e., channelling of material to produce a lobe in bedrock depressions, or movement as a broad sheet where no depressions exist. Lobe fronts are usually a few meters wide and are best developed on slopes between 5° and 15°. Sheets, on the other hand, may have fronts several tens to a hundred meters long, and are best developed on slopes between 5° and 7°.

Both lobes and sheets are usually multiple, i.e., a succession of lobes or sheets, one atop the other in stair-like fashion. Figure 3 shows the terminus of a solifluction sheet moving over the surface of a delta deposit 3 km northwest of Base Camp. The front of the sheet is 0.2 to 0.5 m high and is nearly continuous for several hundred meters. The sheet is composed of ground moraine and intermixed sands and gravels from higher kame deposits. The ground moraine is not particularly bouldery in this area, no more than 5 per cent of the surface showing boulders.

Figure 4 is a sketch cross-section in the front of the solifluction sheet illustrated in Fig. 3. There is a concentration of boulders laid in imbricate fashion at the overriding margin. Inter-boulder voids occur for nearly 0.5 m into the sheet. The frequency of large boulders decreases as the sheet is penetrated and decreases near the surface (see Table II for mechanical analysis). The intense deformation of the bedded delta deposits and the smeared and stretched character of the organic matter indicate that the sheet has not merely crept over the delta but has actually pushed into and deformed it. Smaller pits dug farther upslope show that the fine and medium sands and silts near the permafrost table, which in August was at a depth of about 1 m, were very compact and would become "quick" and viscous with normal digging. The moisture, by weight, in this material is 18 to 20 per cent.

TABLE II. PHYSICAL DATA FOR PROFILE 11, APPLICATION TO CROSS-SECTION FIG. 4.

Sample No.	Sand	Silt	Clay	Bulk Density	Plasticity Index	Non-flow Moisture %	Flow Moisture %
Taq 11 5-45 cm	61.0	36.6	3.1	1.63	NP	10.25	14.33
Taq 11 45-73 cm	59.4	38.6	2.5	1.75	NP	12.75	15.24
Taq 11 97-112 cm	63.4	35.5	1.8	1.47	NP	15.70	22.50

Tests showed the material to be non-plastic. Further tests showed that in most cases an addition of 2 to 3 per cent moisture was sufficient to cause the mineral soil to go from a rather friable, aggregated form to the viscous state when subjected to slight jarring. Similar phenomena have been noted by Sørensen, (1935) and Jahn (1946). When the viscous state had been reached, a film of water appeared on the surface. After setting a few minutes, the mineral soil below the surface water film was compact, rather dry, and vesicular, similar to wet concrete which has undergone vibration, i.e., compaction has occurred and the water is expelled.

Field moisture values for the "quick" material were usually well above the critical values obtained for the same material in the laboratory. It is believed that moisture and texture play the most important roles in the flow of these soils.

The near lack of large boulders in the upper 0.5 m of the sheet and a boulder concentration at the margin suggest that boulders may have been brought to the edge by a more rapidly moving surface and gradually rolled under. The slower moving, denser (see Table II) subsurface gradually reacted on them to produce the imbricate character. It would appear that in the spring when soil moisture is high the stability (consistency) of the soil is radically changed near and on the surface, with the result that micro-mudflows occur (Fig. 9), as well as flowage in the upper 10 to 20 cm. As thawing progresses, sufficient moisture is liberated from the melting of seasonal frost to produce soil instability at progressively deeper layers. In this manner the entire sheet advances. The result is similar to that pictured in Fig. 7, although the mechanics of movement differ.

Drying of the surface in many areas results in cracking in a more or less polygonal pattern, although cracks have been noted which now essentially parallel the advancing front of the sheet. Excavation normal to the crack reveals considerable distortion on either side of the crack (Fig. 6). It is suggested that these cracks are primarily the result of desiccation and that lateral subsurface soil flow relative to the surface may accentuate them and account for the associated deformation. The development of the cracks also provides zones of relief along which subsequent lobes may start (Fig. 5), the result being multiple solifluction sheets.

On the southeast-facing slope of the Tasersiaq Valley, where solifluction lobes dominate, an excavation of one lobe showed essentially the same cross-section as that shown in Fig. 4. The frontal rise of the lobe was 1 m. The percentage of large surface boulders, 10 to 20 per cent, is much greater on this slope. Excavation again revealed a concentration of boulders at the lobe margin. Their sizes and frequency decreased as the cut was extended back. The extreme contortion noted in Fig. 4 was not present here because of the absence of bedded sands. The process of lobe formation is considered to be the same as for the sheet.

Of particular interest in this cross-section (Fig. 5) are the pendant inclusions of organic matter, which show a lessening of dip toward the lobe margin. These pendants represent tensional cracks filled with organic matter. Their attitude and progressive stretching out represent surface motion considerably greater than that in the subsurface. They may also represent incipient lobes.

Carbon-14 dates were obtained for the two solifluction features in Figs. 4 and 5. A date of 1695 $\pm$ 140 years B.P. (Isotope No. I-1095) was obtained on frozen peat 2 m from the frontal margin and at a depth of 1.6 m (Fig. 5). A date of 935 $\pm$ 120 years B.P. (Isotope No. I-1096) was obtained from unfrozen organic matter 1.7 m back from the lobe front and 0.93 m below the surface (Fig. 5). It was hoped that such dating would give not only relative ages of the features but relative rates of movement as well. Both dates were much too old. The solifluction sheet (Fig. 3) from which the 1695 B.P. date was obtained overrides a delta deposit related to a high level of Lake Tasersiaq, which is not more than a few hundred years B.P. This dating is based on evidence obtained from glacial geology investigations (Crowl, personal communication). Reliance is placed on the geologic evidence rather than the single C-14 date. Burns (personal communication) has suggested that organic material in even the shallow A horizons may range over several thousand years from top to bottom of the horizon because of the slow decomposition rates in arctic environments. Because of the contortion and mixing which occur in solifluction, any date obtained on this buried material would be a composite date which reflects neither the age nor the rate of movement of the feature. It is hoped that more detailed work next year will shed light on the significance of even composite dates.

Slump debris with imbricate structure is depicted in Fig. 7. Where such deposits occur they are associated with active nivation snowbanks and are restricted to the northeast-facing slope. They display certain similarities to solifluction lobes, particularly in the imbricate arrangement of rocks at the frontal margin. Many of the rocks dip 35° to 37° into the slope. A second similarity is the large amount of void space between individual fragments on the front. The deposits differ from solifluction lobes in that a vegetation cover is lacking. The nivation snowbank on the upslope side provides ample water which moves fines over and between the large rocks and completely saturates this material. The entire mass is interpreted as a slump feature and not a product of the snowbank, the imbricate structure being formed by a rapid slump of saturated till. Nivation sapping and running water tend to keep the inter-boulder spaces on the margin open.

Many boulder-rampart terraces that are now heavily encrusted with lichens and support a wet meadow on the tread may represent "fossil" slumps. It is logical to assume that the slumping process was particularly active immediately after deglaciation. Large areas with little or no lichen encrustation and associated with modern perennial snowbanks indicate that the snowbanks were much larger until comparatively recent times. Some of these rock-rampart terraces will undergo solifluction, and no doubt will retain the imbricate boulder front.

Mudflow

Mudflow is an important agent of mass-wasting in almost all climatic regions. It is, however, best developed in arid and semi-arid areas where it may be the most important factor in mass-wasting. Washburn (1947, p. 86) states, "Mudflow is not usually associated with Arctic regions. Yet it occurs in them and locally at least may be of considerable importance."

Micro-mudflows.--Micro-mudflows, particularly on the drier south-facing slopes, are of great importance in mass-wasting in the Sukkertoppen area. Figure 8 illustrates a typical slope prone to mudflow, and Fig. 9 pictures a mudflow which occurred during the summer of 1963. The slope in Fig. 8 has many lobate terraces, which range in length from 0.5 to 6 m and from a few tenths to several meters in width. The terraces are usually compound, i.e., they have a succession of lobate terraces upslope. The successive frontal lobes usually support some vegetation. They rise several centimeters above the incline of the terrace immediately downslope. Often both the lobate edge and the terrace slope show convolutions suggestive of surface flowage.

Where the terraces are best developed, the slopes are usually dry in middle and late summer because they are freed of snow in the early spring.

In August, 1963, there was considerable evidence of recent nudflow activity on these slopes. The flows occurred between the first week in July and late August, probably during or immediately after the heavy rain of 6 July. On this date 13.5 mm fell, roughly 40 per cent of the total recorded between 23 June and 1 September.

The terraces apparently became thoroughly saturated to the point of flowage. In some cases the frontal rim of the lobe was breached, releasing the unstable, saturated mass behind. In other instances the frontal lobe simply flowed over the next succeeding terrace with only minor breaching of the lobe. The larger flows moved blocks as large as 20 cm, 1 to 3 m downslope, and finer sandy material was moved two to three times that distance.

The mineral soil involved in the flow appeared to have the same physical properties as the "quick," vesicular material described earlier. Certain of the terraces can be made to flow by pounding with a shovel blade on the more or less flat area upslope of the frontal lobe and rim. Continued pounding turns this area into a quaking mass. Cracks open parallel to the frontal lobe and a viscous mineral soil is extruded through them. The extruded soil has a film of water on the surface, yet cannot be penetrated by pushing one's finger against it. When this material is broken open it appears vesicular. Tests show that the material will flow at a moisture content of 13 per cent by weight.

The slopes showing micro-mudflows are very unstable in early spring during snow melt and at times of heavy summer rains, but the frequency of such rains is not yet known.

Large mudflows and debris slides.--Large mudflows, involving hundreds or thousands of tons of debris, have occurred in the Lake Tasersiaq area in the past. A well-developed example of a large mudflow is on the southwest-facing slope of the Tasersiaq Valley north of The Island (Frontispiece). The flow moved down a 20° slope and spilled into the lake. Now only prominent gulley embankments remain.

There are indications of mudflow on the northeast-facing slope near the head of Mudflow Creek. The evidence is primarily gulley embankment and scattered patches of debris along the valley sides. Breached high-level kame-terraces and fan deposits downslope suggest mudflow activity on other areas of this slope. The flows may be quite old, dating perhaps to the last ice recession from the valley. There is no evidence of recent large mudflows.

Debris slides are rather common on the steeper portions of the southwest-facing slope. Several are known to have occurred after 4 July 1963. The term "debris slide" is used here with the realization that in some instances the material may have been saturated. In general, micro-mudflows do not occur on this slope. The extent to which debris slides contribute to mass-wasting is not known, but it may be very significant.

Rockfall and rill-wash

Rockfall and the resulting talus and scree accumulation are impressively developed on southwest-facing escarpment slopes, principally on the northwest side of Lake Tasersiaq (see Fig. 10b). The over-steepened upper slopes, coupled with the jointed character of the bedrock, provide optimum conditions for rock-fall and the production of long straight scree slopes.

The scree on the southwest-facing slope of Tasersiaq Valley shows, almost without exception, a gradation from fine fragments near the top of the slope to large blocks, several meters in diameter, near the toe. At a break in slope from 27° to 15° the straight inclined scree gives way to parallel or sub-parallel rock streams, which, as the slope decreases, give way to block-bordered polygons (Fig. 1).

Slopes recently freed of perennial snowbanks are just now being affected by frost disintegration and are producing a scree by rockfall. Well-developed rock fans occur at several points at the end of deep, narrow, open joints.

Rockfall is a very important process in mass-wasting on the upper slopes and in the initial production of slope form. It gives way with decreasing slope, and perhaps, with time, to solifluction.

Measured Movements

Quantitative measurement of slope movement was carried out at three sites between 26 June and 23 August 1963. Two sites were established on the northeast-facing slope and one on the southwest-facing slope of the Tasersiaq Valley (Frontispiece). Each site was measured at least twice during the summer.

Methods.--Each of the three sites consisted of 12 stakes, 17 x 2 x 2 cm. The stakes were inserted 15 cm into the ground. The positions of the stakes were selected with reference to (1) the character of the slope, i.e., an effort was made to cover as many different conditions of microrelief, vegetation, and moisture as possible; and (2) the length of the baseline, which was determined by the position and extent of bedrock outcrops. In addition to placing the stakes in the maximum number of different slope conditions at any one site, an effort was made to choose slopes most typical of the valley in general (Fig. 10).

At each site a baseline was marked off on a bedrock outcrop. Because of the nature of the outcrops the baselines were fairly short. After the baseline had been established, the stakes were set, and vertical and horizontal angles were sighted to the base of a nail driven into the top of each stake. Surveying was done with a DKM 1 theodolite.

Angles were turned successively for each stake, first from one end of the baseline and then from the other. A backsight and a foresight were made on each stake. No separate set of angles was turned for each stake, but rather a cumulative angle was turned through the 12 stakes from each base point.

Because some stakes (1 through 4, site I) were located at distances greatly exceeding three times the length of the baseline, considerable error occurred in the final calculations. The maximum possible error at a distance of 92 m. (stake 1, site I) amounted to ± 3.5 cm, or an error of 0.4 per cent. Using a five-minute reproducibility error for the instrument, which is somewhat more than is specified for the DKM 1, the error is proportionally smaller at lesser distances. Mechanical error becomes significant only when measurements for the more distant stakes are considered.

Results.--Site I (Fig. 10a) on the northeast-facing slope is fairly typical of large areas of this slope where solifluction and creep is blocked by either an outlier of bedrock or an ice-contact feature. Its position relative to a snowbank or nivation hollow is also typical. In this case the snowbank is small and melts completely by mid-July. During the melt, the ground downslope is wet and portions have running water on the surface. After melt, the area dries rapidly and the surface is subject to cracking.

Site II (Fig. 10b) on the opposing valley slope is characteristic of most of this side of the valley below the scree slopes. Solifluction and creep are interrupted by bedrock outcrops. The outcrops strike discontinuously along the valley for several miles. Solifluction has filled in behind and in many cases breached them, imparting a terraced appearance to the slope. Snow banks disappear on this slope by June. Many areas remain wet throughout the summer and this is attributed to springs. For the most part, the ground dries rather early in the season.

Site III (Fig. 10c) on the northeast-facing slope is much like site II; however, it differs from Site II in that the slope is kept very wet throughout the summer by a large, late, long-lasting snow bank.

Tables I through III are assessments of each stake position by site; Fig. 11 represents the relative stake position by site. The arrows are the resultant vectors of X and Y movement resolved on the horizontal plane. The length of the arrows is proportional to the movement. Table IV gives movements in centimeters for the X and Y and Z directions for each stake with regard to a single base point.

An inspection of Fig. 11 indicates areas in both sites I and II where pronounced movements occurred. These areas correspond to well-formed solifluction lobes. The direction of movement is governed by the configuration of the slope. Neither area of strong movement is well drained. Although the lobe at site II was dry at the surface, excavations nearby indicate a saturated zone not far below the surface.

Movement away from the baseline characterizes site I. Such movement may well be the result of surface contraction on drying during the summer. The reversal in flow direction with respect to the ends of the baseline reflects the slope configuration and the influence of the bedrock outcrop against which the slope material moves.

If the errors discussed above under Methods are applied to Fig. 11, then the maximum movement of the lobe at site I must be reduced by 3.5 cm. Although this error decreases proportionally as the baseline is approached, it is sufficient to cancel out most of the slight movements on both sites I and II.

The effect of the saturated conditions resulting from a late-lying snowbank is manifest at site III (Fig. 11). Here, as at sites I and II, the direction of movement is controlled by the configuration of the slope. Magnitude of movement at site III exceeds the maximum at sites I and II by nearly three times, and considerably exceeds the probable mechanical error.

SUMMARY

The ice-free Lake Tasersiaq area, marginal to the Sukkertoppen Highland Ice, is underlain by jointed granite and gneiss which have a thin veneer of ground moraine. Kame terraces of several generations occupy the valley bottom and occur at different elevations on both the southwest- and northeast-facing slopes.

With local exceptions, patterned ground is not well developed in the area. Solifluction lobes occur on both slopes, but solifluction sheets are essentially restricted to the more gentle northeast-facing slope. Many sheets and lobes show an imbricate arrangement of boulders at their frontal margins. These features appear to be of rather recent age (several hundred years), and to have developed as a result of critical soil moisture and texture relationships inherited from the till and kame deposits which mantle the slopes.

Slump features which show imbrication of boulders on their frontal margins are common, both as recent and "fossil" forms. Micro-mudflows and debris slides are perhaps the most active features of the area in terms of volume of material moved downslope. There is considerable evidence that large mudflows were active in the past.

Measured rates of movement range from less than 1 mm to more than 40 cm in a three-month period. The rate and amount of movement is strongly influenced by the position of late lying snowbanks. The direction of movement is controlled to a large extent by the configuration of the slope.

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TABLE III

STAKE NO.	SLOPE ANGLE	VEGETATION* MICRORELIEF, MOISTURE CONDITIONS
1	22°	Carex sp., mosses; crest of solifluction lobe at lip of nivation hollow.
2	19	Carex sp., mosses, complete cover, wet.
3	7	Carex sp., mosses, complete cover, wet.
4	15**	Betula sp., Carex sp., Cassiope tetragona, flat area just downslope from unvegetated terrace lobe, moist.
5	19	Carex sp., Cassiope tetragona, moist.
6	14	Scattered Carex sp., mosses, running water.
7	9	Betula sp., Carex sp., Cassiope tetragona, hummocky, moist.
8	15	Carex sp., mosses, very wet.
9	14	Carex sp., mosses, moist.
10	8	Carex sp., Dryas integrifolia, margin to stony circle, dry.
11	15	Carex sp., Dryas integrifolia, at margin of small terrace lacking vegetation, dry.
12	14	Carex sp., Dryas integrifolia, mosses, crest of small solifluction lobe, moist.

SITE I, 26 June 1963

* only dominant plants listed
** general slope

TABLE IV

STAKE NO.	SLOPE ANGLE	VEGETATION* MICRORELIEF, MOISTURE CONDITIONS
1	2°	Scattered Carex sp., mosses, solifluction terrace, stake at frontal margin of lobe, moist.
2	16**	Carex sp., mosses, rim of small multiple solifluction lobe, dry.
3	20	Dryas integrifolia, mosses, near base of outcrop, dry.
4	20	Saxifraga sp., lichens, dry.
5	2	Dryas integrifolia, Carex sp., mosses, wet.
6	3	Dryas integrifolia, Saxifraga sp., grasses, lichens, moist.
7	7	Mosses, Rhododendron lapponicum, grasses, wet.
8	10	Salix sp., grasses, dry.
9	23	Carex sp., mosses, grasses, side margin of solifluction lobe. Lobe surrounded by Betula sp., dry.
10	20	Vegetation as at 9. Stake 57 cm from frontal margin of solifluction lobe, dry.
11	20	Vegetation as at 9. Stake at side margin of solifluction lobe, dry.
12	16	Dryas integrifolia, Carex sp., insipiant mudflow or debris slide, dry.

SITE II, 4 July 1963

* only dominant plants listed
** general slope

TABLE V

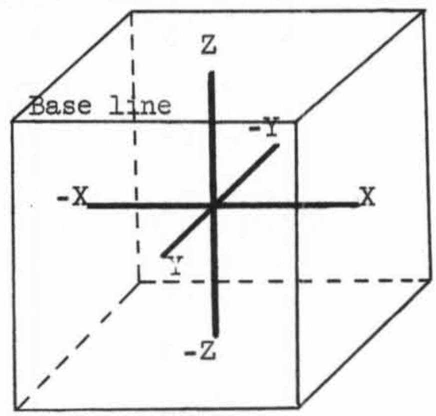
STAKE NO.	SLOPE ANGLE	VEGETATION* MICRORELIEF, MOISTURE CONDITIONS
1	21°	Scattered mosses, mostly bare ground, very wet, running water.
2	18	Mosses, scattered Carex sp., just below out-crop, dry.
3	10	Thick and complete cover of mosses, moist.
4	18	Same as 3.
5	9	Scattered mosses and Carex sp., dry.
6	12	Scattered mosses and Carex sp., scattered Eriophorum scheuchzeri, wet.
7	17	Scattered Eriophorum scheuchzeri, very wet, some rumming water.
8	15	Scattered Eriophorum scheuchzeri and a blanket of mosses, surface is bouldery, wet.
9	9	Same as 8.
10	10	Mosses, Carex sp., Dryas integrifolia, surface is bouldery, moist.
11	12	Carex sp., mosses, very wet, some running water
12	17	Completely vegetated with Carex sp., and mosses hummocky, wet.

SITE III, 17 July 1963

* only dominant plants listed

TABLE VI

Site I	X, cm	Y, cm	Z, cm*
1	14.34	12.04	3.79
2	9.76	8.74	1.33
3	7.50	6.02	10.85
4	0.13	- 1.47	0.68
5	- 1.56	- 3.42	- 1.32
6	0.56	- 0.98	0.24
7	- 2.46	- 2.78	0.19
8	- 1.29	- 2.49	0.92
9	0.07	- 1.10	1.41
10	- 0.22	- 2.44	1.58
11	0.22	- 1.27	0.36
12	0.33	- 0.37	0.56
Site II			
1	0.44	0.23	0.12
2	0.72	0.46	- 0.11
3	- 0.29	0.01	- 0.22
4	- 0.51	0.20	- 0.05
5	- 0.12	- 0.53	0.70
6	- 0.45	- 1.35	0.60
7	0.71	1.99	- 0.76
8	- 0.70	- 7.36	2.80
9	0.58	- 8.04	2.74
10	0.83	- 6.12	1.80
11	0.67	- 6.09	1.87
12	1.06	- 0.94	0.28
Site III			
1	5.37	-10.03	5.88
2	4.11	-2312	10.41
3	6.43	-36.73	14.82
4	15.86	-42.76	17.83
5	- 7.84	-40.80	15.78
6	12.85	-31.25	11.80
7	-----	------	-----
8	- 7.11	-42.09	27.03
9	-19.11	-47.67	16.84
10	- 0.29	1.46	0.68
11	-----	------	------
12	- 0.49	3.73	1.75



Reference solid for X and Y directions of movement, sites I, II, and III.

* Accuracy of vertical angle is much less than for the horizontal angles.

Change from 0 in X and Y and Z components of movement by stake for each site. Figures are in centimeters and are uncorrected for surveying inaccuracies.

LIST OF ILLUSTRATIONS

Fig. 1 - Sorted polygon on the southwest-facing slope of the Tasersiaq valley. The pictured area at the site of the polygon is approximately 6 meters wide. August, 1963

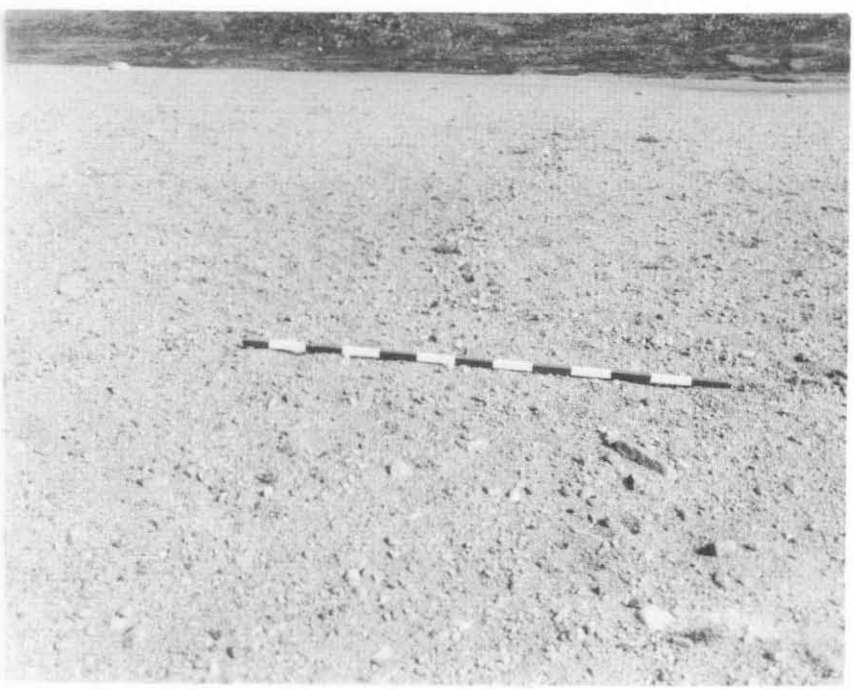


Fig. 2 - Sorted polygon on kame terrace near Glacier B. Decimeter pole is 1.2 m long. Polygon borders join just behind pole. August, 1963

Fig. 3 - Solifluction sheet, 3 km northwest of Base Camp. August, 1963

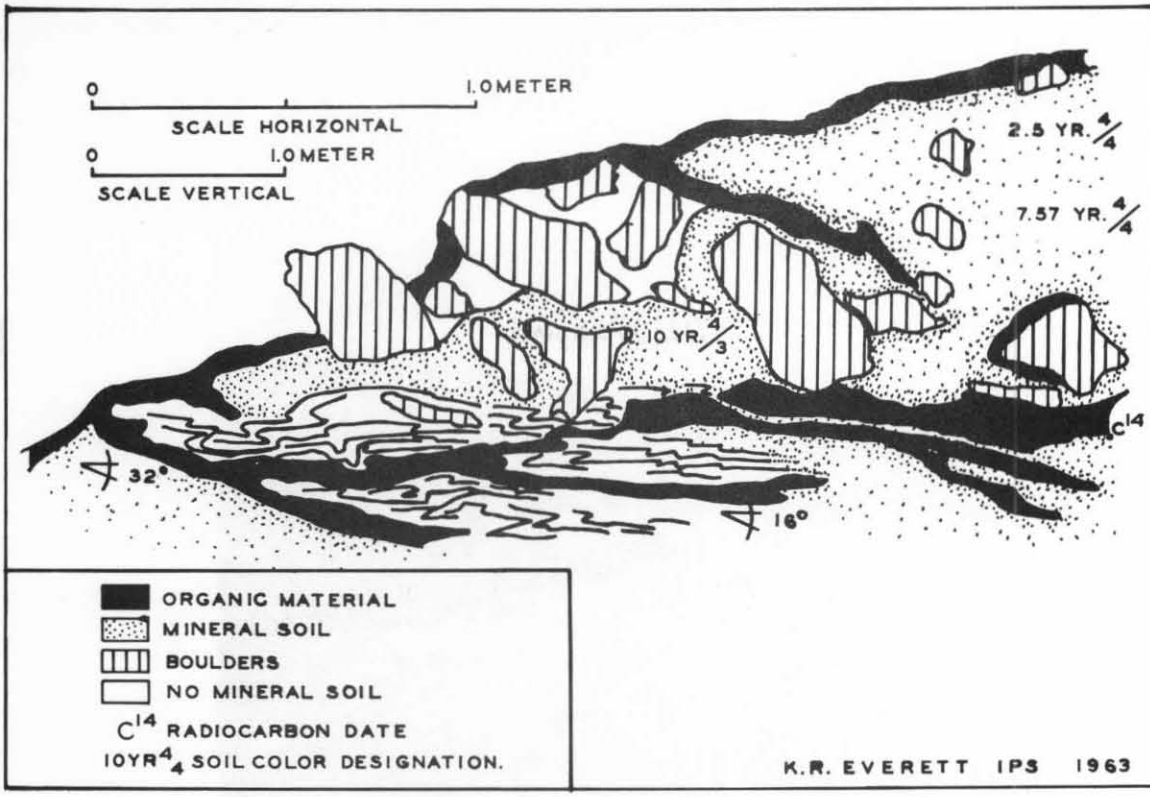


Fig. 4 Cross-section of solifluction sheet in Fig. 3, northeast-facing slope

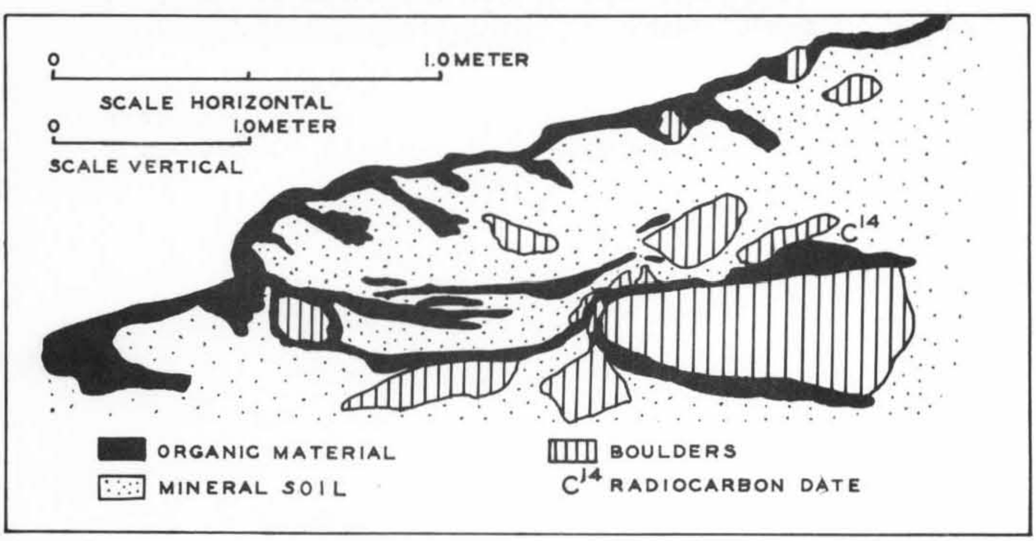


Fig. 5 Cross-section of solifluction lobe, southwest-facing slope

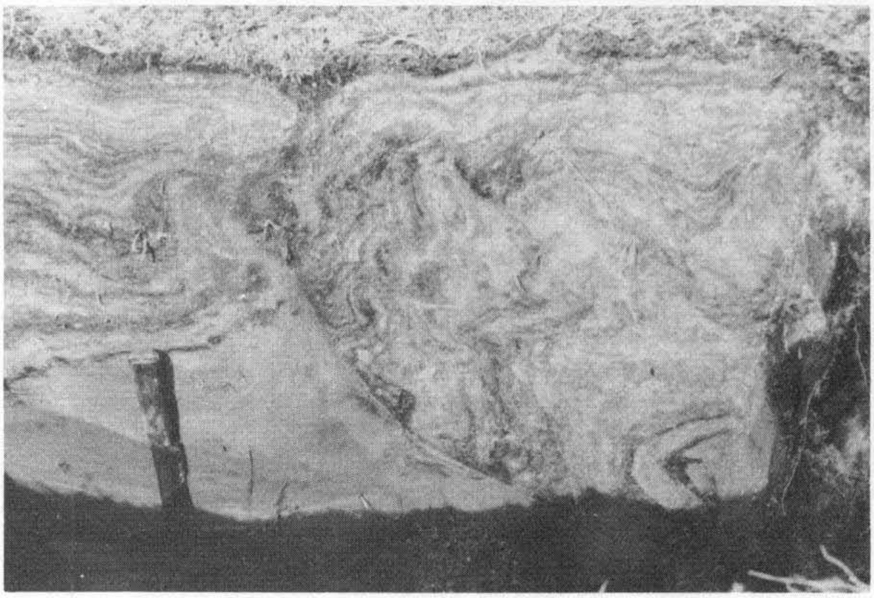


Fig. 6 - Distortion on either side of a contraction crack. Slope decreases from right to left. Slope angle 2°. July, 1963

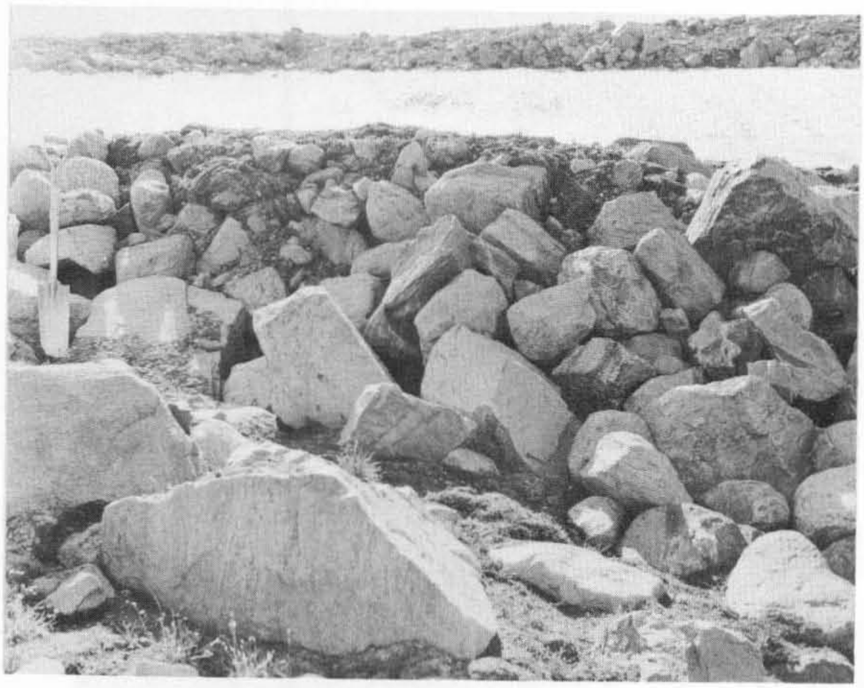


Fig. 7 - Slump debris showing imbricate arrangement of blocks along front. Nivation snowbank behind slump. Note open space between blocks and the decrease in fragment size above the blocks. July, 1963

Fig. 8 - South-facing slope of Camp Creek. This slope has many terracettes and is prone to micro-mudflows. Slope angle 10°. August, 1963

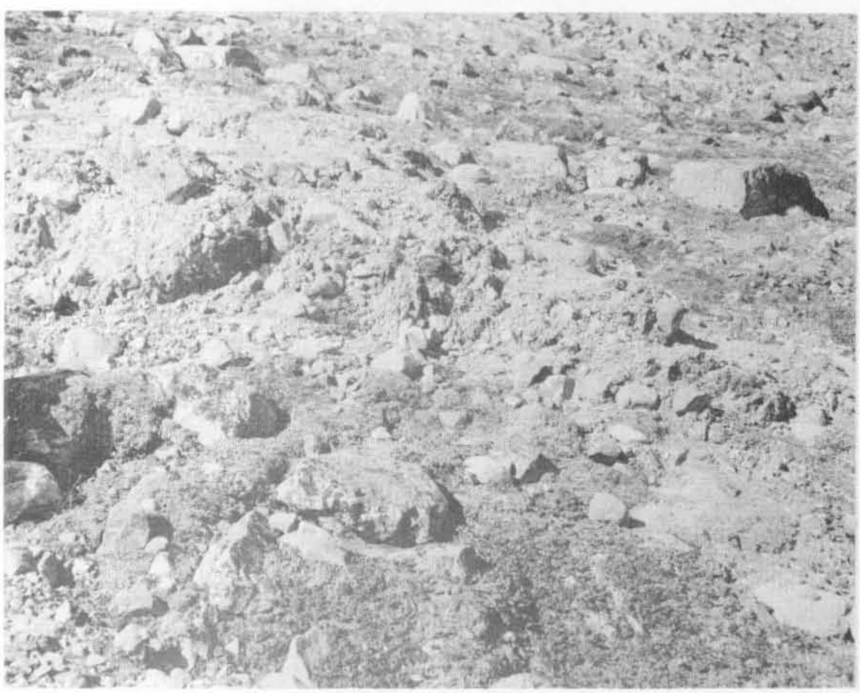
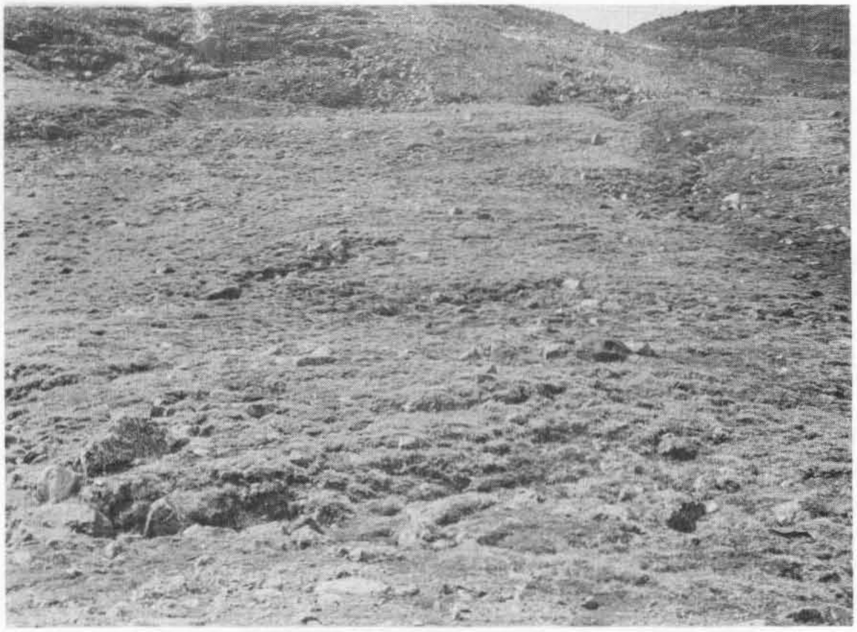
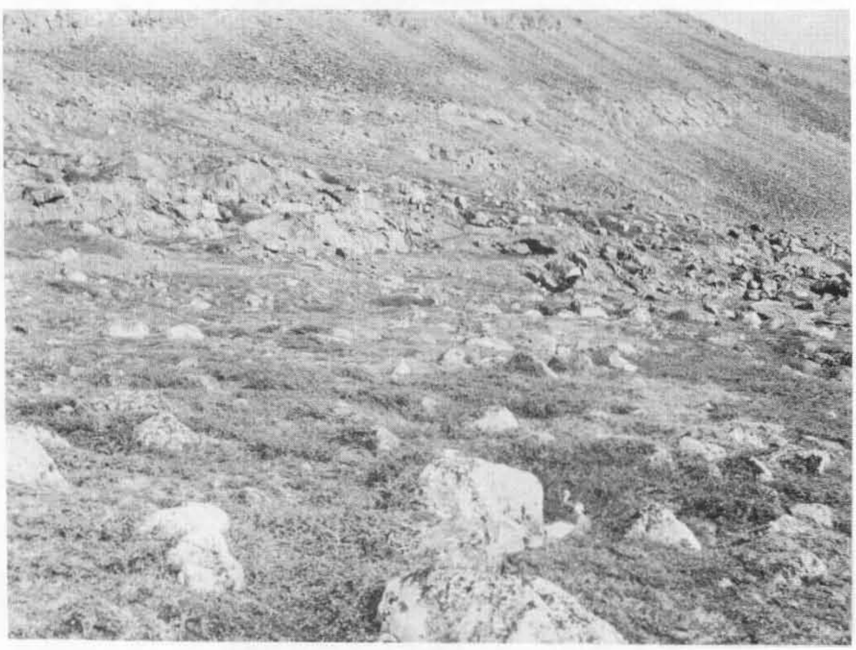


Fig. 9 - Micro-mudflow on slope in Fig. 8. August, 1963



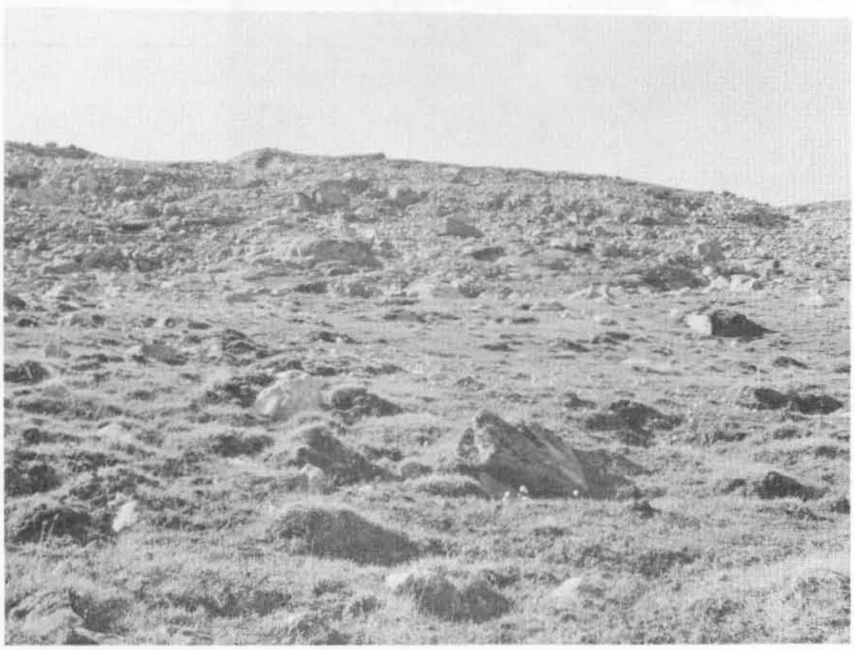
A Fig. 10

General view of Site I. Northeast-facing slope looking upslope from the baseline. July 18, 1963



B

General view of Site II. Southwest-facing slope looking upslope toward baseline. Note the long scree slopes in the background. August 7, 1963



C

General view of Site III. Northeast-facing slope looking upslope toward baseline. August 29, 1963

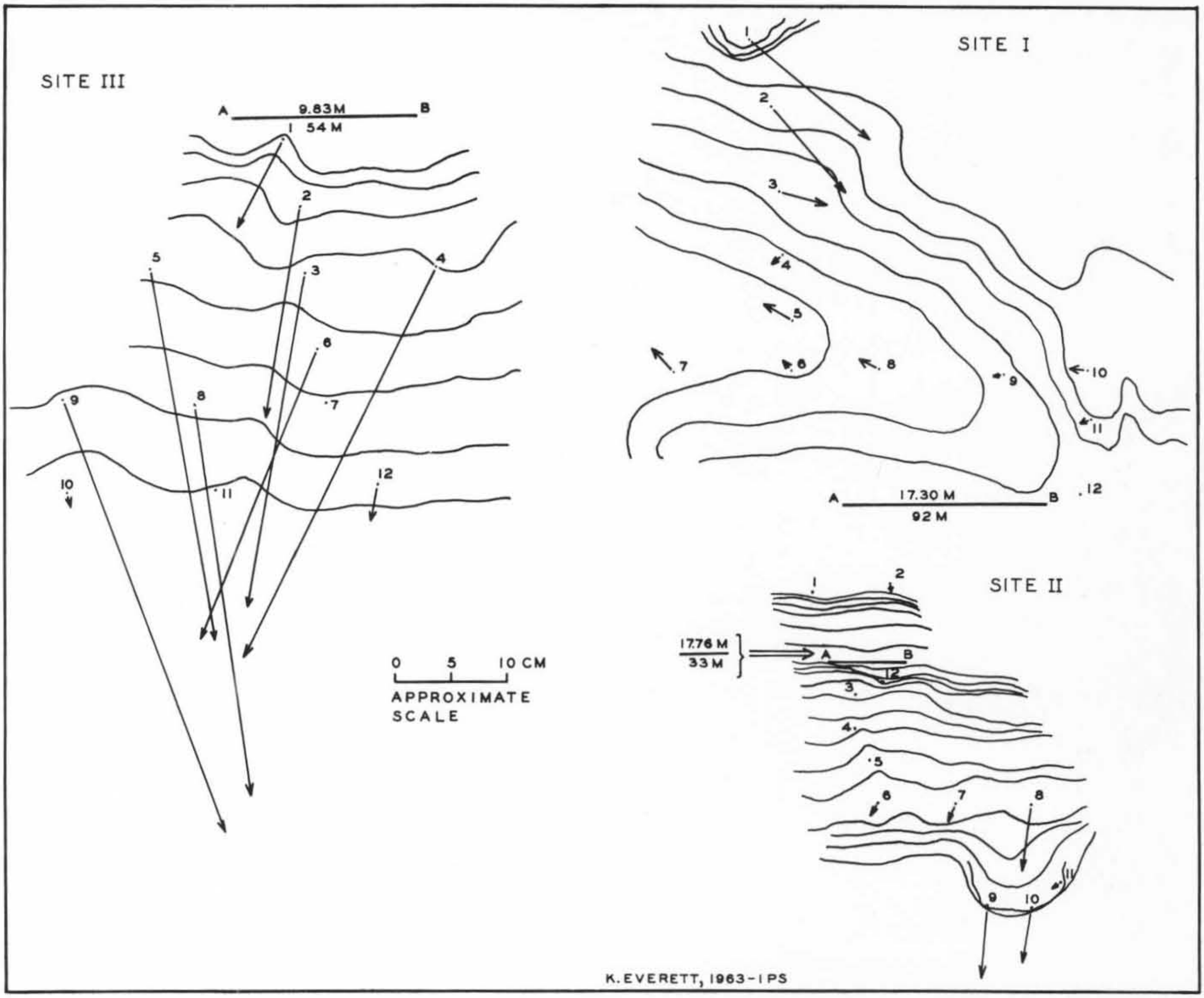


Fig. 11 - Sketch map showing the relative magnitude of movement by site

* The number above the line indicates the length of the baseline, the number below the line indicates the distance to the most distant stake. Contour lines are actually form lines and no scale is implied.

PRELIMINARY REPORT ON THE LIMNOLOGY OF SEEPAGE AND GLACIAL-FED LAKES, WESTERN TASERSIAQ AREA, GREENLAND

by

DERRY KOOB

INTRODUCTION

In the summer of 1963 a preliminary survey was made of some 20 lakes of the Tasersiaq region of southwest Greenland. This was accompanied by weekly detailed sampling of seven of the lakes. An eighth lake, Lake Tasersiaq, was sampled three times during the summer season. The locations of the study lakes are indicated on the accompanying map (Frontispiece). The programs outlined below will be continued and enlarged during the 1964 summer field season so as to complete the scientific program. Upon completion of analysis of the 1964 data, another report will be prepared for publication in a scientific journal.

Lake Tasersiaq is a glacially-deepened river valley; Lake Quantum occupies the previous drainage channel from glacial Lake Tasersiaq. These two lakes and Dinner Fork Lake now receive a major portion of their inflow from glacial melt water. The remaining five lakes are of the seepage type. However, North Overshoe is connected to Dinner Fork early in the season and Lake Caribou probably receives some subsurface drainage from Lake Quantum. Morphometric data for the eight lakes are given in Table I.

TABLE I. MORPHOMETRIC DATA FROM THE EIGHT STUDY LAKES

Lake	Type	Maximum Depth, m	Approximate Surface Area	Secchi Disc, m
High George	Seepage	3.5	1 hectare	> 3.5
Low George	Seepage	2.0	2	> 2.0
Two Duck	Seepage	3.5	3	> 3.5
Caribou	Seepage	3.5	9	> 3.5
North Overshoe	Seepage	4.0	2	> 4.0
Dinner Fork	Glacier-Fed	2.0	4	0.3
Quantum	Glacier-Fed	27.0	100	0.2
Tasersiaq	Glacier-Fed	13.5*	50 km^2	0.1

* The maximum depth given for Lake Tasersiaq is from a station near base camp. Depth soundings were not made south of Camp Creek outlet.

Bocher (1949) classified the freshwater lakes of Greenland according to the concentration of salts in the water. He did not study lakes near the margin of the ice caps which receive meltwater containing large amounts of glacial silt. Røen (1962) included six glacier-fed lakes in his extensive study of the distribution of freshwater entomostraca. He proposed two major freshwater categories: (1) lakes with large quantities of suspended material, and (2) lakes with clear water. Category 2 was subdivided into three categories on the basis of increasing salt concentration.

The three glacier-fed lakes of the present study belong in category 1 of Røen; the seepage lakes are of type 2. No lakes high in salt content similar to those found by Røen or Bocher are present in the study area.

METHODS

Sampling in each of the lakes was done from a single sampling station at the approximate center of each lake. Temperature readings were made with an induction salinometer at the surface and at one meter intervals to the bottom. Relative transparency values were obtained by use of a standard white 12 cm Secchi Disc. Oxygen concentration was measured in the field using the unmodified Winkler method.

One-liter surface water samples were collected in polyethylene bottles and returned to Columbus, Ohio, for chemical analyses by the U. S. Geological Survey Surface Water Division. Analysis of suspended material was made in the particulate laboratory of the Institute of Polar Studies of The Ohio State University.

Biological samples were collected with a Kemmerer water bottle and filtered through a plankton bucket with a No. 20 silk bolting cloth. The organisms from 10 liters of water were concentrated to 10 ml including a small amount of CRAF preservative. Counts of the organisms were made using a Sedgwick Rafter cell and Whipple ocular at 100 X magnification. Entire 1 ml aliquots were used in enumerating the zooplankton and less abundant phytoplankton. For the more abundant algae, 20 fields per sample were counted. Both depth and seasonal abundance distributions were graphed for all organisms found. However, in the absence of significant variation in depth distribution, the results are expressed as the number of cells or organisms per liter averaged over the entire column of water sampled.

RESULTS

Temperature

Ice was present in all of the lakes upon initiation of sampling during the last week of June. Complete thawing occurred in the most shallow lakes first. Lake Tasersiaq was not ice-free until July 10. Following erratic fluctuations in both air and water temperatures during the first two weeks in July, the temperature of the shallow seepage lakes closely followed air temperature, increasing to a maximum in the second week in August and then decreasing steadily for the remainder of the season. The water temperature of these lakes was always above the daily mean air temperature. On July 20, following a two-day period of clear calm weather, the temperature of Low George reached 11.5°C, exceeding the maximum air temperature of that day by 0.5°. This slight superheating of the water was probably due to absorption of light by the almost black moss cover on the bottom of the lake.

Maximum surface water temperatures were recorded from the shallow seepage lakes during the second week in August. They were 13.8°, 13.4°, 13.3°, 12.9°, and 12.8° in High George, Low George, Two Duck, Caribou, and North Overshoe Lakes, respectively. Maximum water temperatures recorded from the three glacier-fed lakes were 11.4° in Lakes Dinner Fork and Quantum and 6.8° in Lake Tasersiaq.

Due to periodically strong winds only ephemeral thermal stratification occurred in the shallow lakes. However, a distinct thermocline was formed in Lake Quantum in August and persisted for more than two weeks (Fig. 1). The river-like characteristic of Lake Tasersiaq accounts for the lack of thermal stratification there.

Oxygen

Oxygen saturation values, corrected for altitude according to the revised nomograph of Mortimer as published in Hutchinson (1957), ranged from 79% in Low George on July 8, to 111% in Two Duck on August 22. Of the 192 oxygen concentration measurements taken during the summer, 182 were 95% or more. Values less than 95% were not found in Lakes Quantum, Dinner Fork, North Overshoe, Caribou, and Two Duck. The moderately low values found in Low George (79% at the 1 m level) and also in Lake Tasersiaq (88% at the 4, 6, and 8 m levels) on the first sampling dates, indicate at least minor oxygen depletion during the winter stagnation period. No explanation could be found for a low value of 81% at the 2 m level in High George on July 28. During the period of thermal stratification in Lake Quantum, no stratification in the per cent saturation of oxygen occurred.

Water Chemistry

A single water sample was collected from each of the eight lakes during the last week in August. Suspended sediment load was measured for the three glacier-fed lakes and for High George. A value of 0.9 ppm in High George was due primarily to the phytoplankton present. Lakes Quantum and Dinner Fork contained 4.8 and 7.5 ppm, respectively. This included both phytoplankton and glacial silt. The value of 139.9 ppm for Lake Tasersiaq was due almost exclusively to glacial silt. Standard chemical analyses were made for the common anions and cations and for dissolved solids (Fig. 2). The amounts of various ions found were, in general, considerably lower than those reported from similar lakes by Bocher (1949) but were comparable to some of the lakes studied by Røen (1962). The three isolated seepage lakes of the present study (High George, Low George, Two Duck) contained relatively large amounts of HCO_3^- and Ca^{++} as compared with the glacier-fed lakes. These also had the highest specific conductance, total anions, and cations. Among the three lakes receiving drainage from the ice caps there was a direct correlation between lake size and the amounts of Mg^{++}, Na^+, K^+, SO_4^{--}, dissolved solids, total cations, and anions.

Ion field diagrams were constructed according to the method of Maucha (1932) (Fig. 3). The areas of the individual segments are proportional to the equivalent concentration of the anions and cations indicated. Four of the seepage lakes (High George, Low George, Two Duck, Caribou) contained predominantly large proportions of calcium and bicarbonate, indicative of a calcareous drainage system. This places them in the bicarbonate type of Clarke (1924). Only North Overshoe contained proportionately more sulfate than bicarbonate, thus belonging to Clarke's sulfate type. The three glacier-fed lakes fall between these extremes. Lake Quantum is only moderately rich in sulfate; Lake Tasersiaq contained nearly equal proportions of bicarbonate and sulfate, while Dinner Fork contained a surprisingly high proportion of chloride to bicarbonate.

Phytoplankton

The populations of phytoplankton varied greatly among the lakes. No net phytoplankton was found in samples from North Overshoe. Two Duck contained small populations of desmids throughout the season. No single algal genus exceeded a maximum concentration of 400 cells per liter. The maximum total concentration of phytoplankton cells was 572 cells per liter on August 8 in Lake Two Duck. Lakes Caribou, and High and Low George were characterized by dominant populations of *Dinobryon divergens* Imhof, *D. cylindricum* Imhof, and *Uroglenopsis americana* (Calkins) Lemmermann. In High George an early season maximum of *D. cylindricum* was rapidly replaced by exponentially increasing populations of *D. divergens* and *Uroglenopsis*. The population concentrations began decreasing prior to termination of sampling on August 19 (Fig. 4). The pattern of population development was similar to this in Caribou and Low George although the maximum concentrations attained were not (Table II). The dominant organisms found in these lakes have been reported as common in arctic Alaska (Prescott, 1963).

TABLE II. MAXIMUM PHYTOPLANKTON POPULATIONS IN THREE SEEPAGE LAKES

(The total values include all net phytoplankton organisms found.)

Lake	*Dinobryon cylindricum*		*Dinobryon divergens*		*Uroglenopsis americana*		Total	
	Cells/ liter	Date	Cells/ liter	Date	Cells/ liter	Date	Cells/ liter	Date
High George	5,152	6/29	831,600	8/11	633,900	8/4	1,006,019	8/4
Low George	550	6/29	2,588	7/28	122,100	7/8	122,267	7/8
Caribou	433	6/30	146	8/22	105,200	7/11	105,380	7/11

Two glacier-fed lakes supported unique phytoplankton populations. Dinner Fork contained large quantities of Gonatozygon sp. A peak of 1,612 cells per liter on August 13 was also accompanied by a bloom of Zygnema sp. and Hyalotheca dissiliens (J. E. Smith) Brebisson. Gonatozygon was found in one other lake, Two Duck; the maximum population attained there was only 6 cells per liter. The dominant algal organism present in Lake Quantum throughout the season was Asterionella formosa Hass. The population concentration varied erratically from a minimum of 26,700 cells per liter on July 9, to a maximum of slightly more than 250,000 on July 27 and August 9. Such a consistently large planktonic diatom population was unexpected in the light of Prescott's statement that in arctic Alaska there are no planktonic diatom floras at all comparable to those in southern latitudes (Prescott, 1963), and Bachman's emphasis on the complete absence of Asterionella formosa in the Greenland lakes studied by him and others (Bachman, 1921).

Three species of Dinobryon were found in Lake Quantum. D. cylindricum was most abundant at the initiation of sampling and decreased in abundance regularly from 6,428 to 112 cells per liter during the season. The development pattern for D. divergens was the reverse, increasing from 0 to 85 cells per liter. D. bavaricum Imhof increased from 0 to 923 cells per liter by August 9. The later species was found in no other lake.

Zooplankton

Of the zooplankton genera found, only Diaptomus sp. was present in all lakes, whereas Lepidurus arcticus occurred only in North Overshoe, and the rotifer Filinia longiseta was found only in Lake Quantum. Rotifers were the dominant zooplankton organisms in all but Two Duck Lake, where cladocerans were slightly more abundant. Cladocerans were present in small numbers in all of the seepage lakes; none were found in the glacier-fed lakes.

CONCLUSIONS

A comparison of the lakes studied showed the following differences between the glacier-fed and seepage lakes:

GLACIER-FED (Tasersiaq, Quantum, Dinner Fork)	SEEPAGE (Two Duck, High George, Low George)
Secchi disc readings less than 0.3 m	Secchi disc visible on bottom
Low HCO_3^- (2-7 ppm)	Higher HCO_3^- (14-16 ppm)
Low Ca^{++} (1.1-2.8 ppm)	Higher Ca^{++} (3.3-4.9 ppm)
Low specific conductance (11-23 micromhos)	Higher specific conductance (37-40 micromhos)

GLACIER-FED (continued)	SEEPAGE (continued)
Large populations of <u>Asterionella</u> or <u>Gonatozygon</u>	Phytoplankton **characterized by desmids and <u>Dinobryon</u> <u>divergens</u>**
Large phytoplankton populations present at time of thaw	Phytoplankton development initiated at time of spring thaw
Cladocerans absent	**Cladocerans** present

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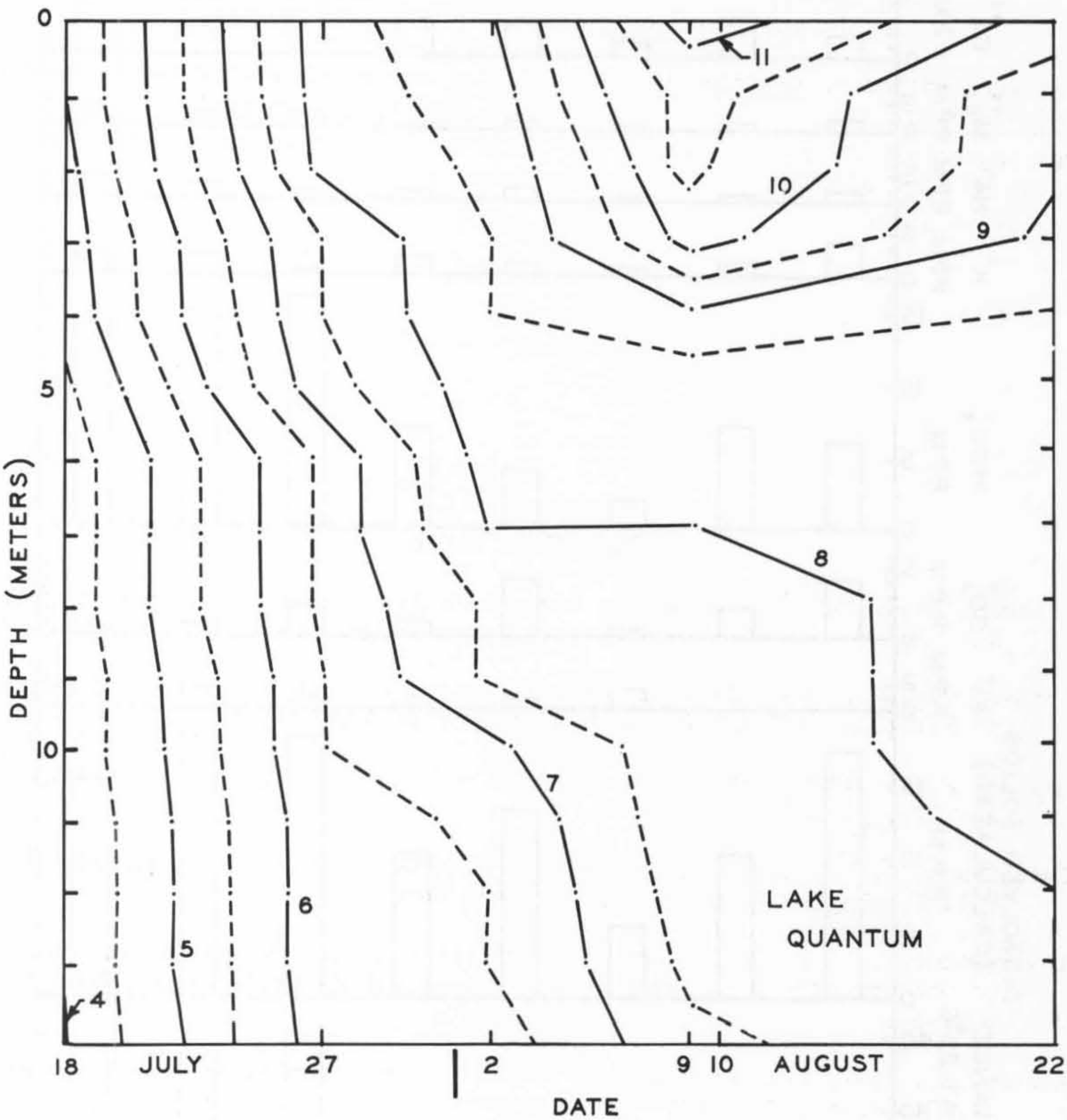

Fig. 1 - Depth-time diagram showing development of thermal stratification in Lake Quantum. Isotherms are given at intervals of 0.5°C.

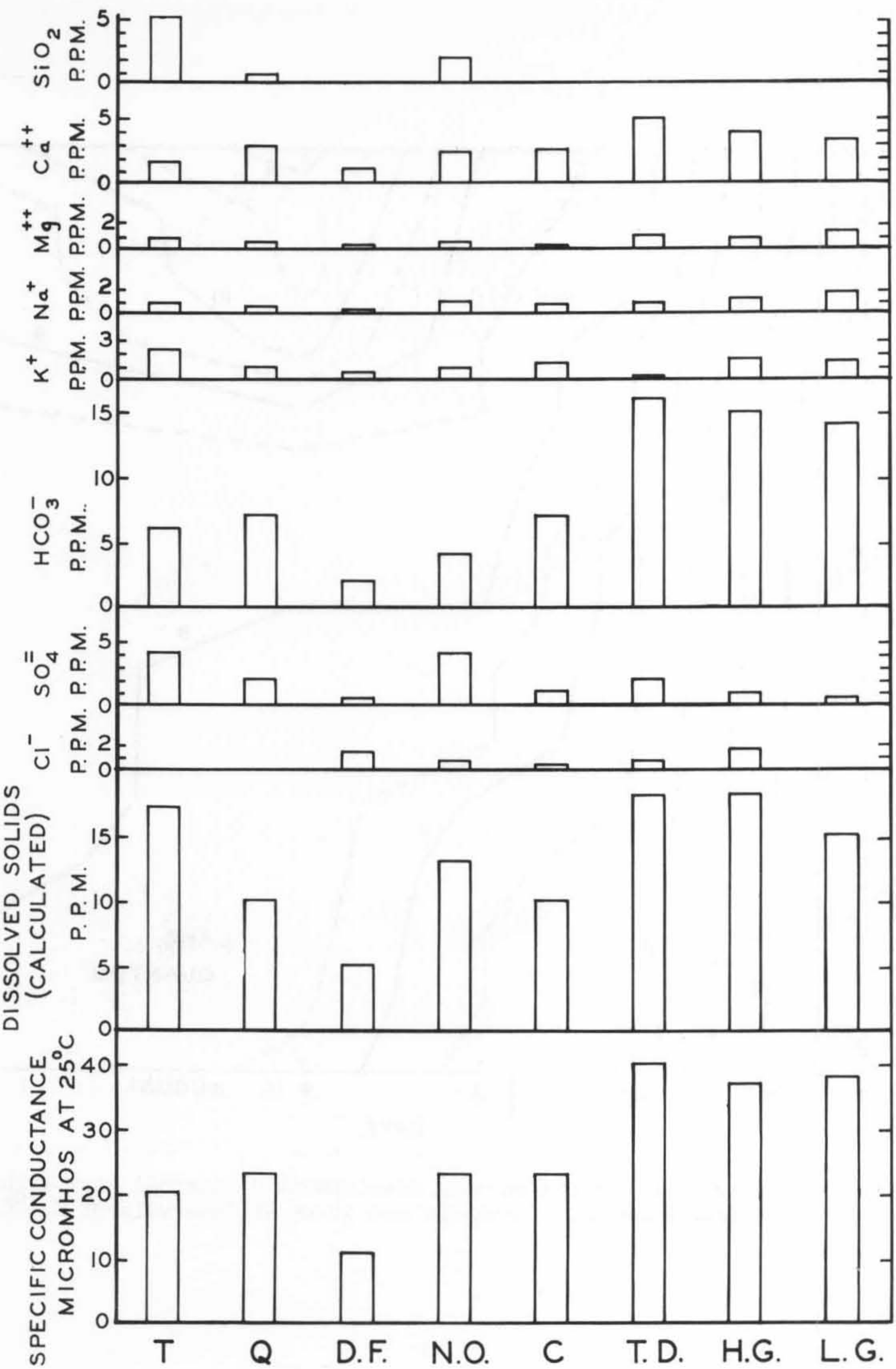

Fig. 2 - Chemical analyses of summer surface waters.

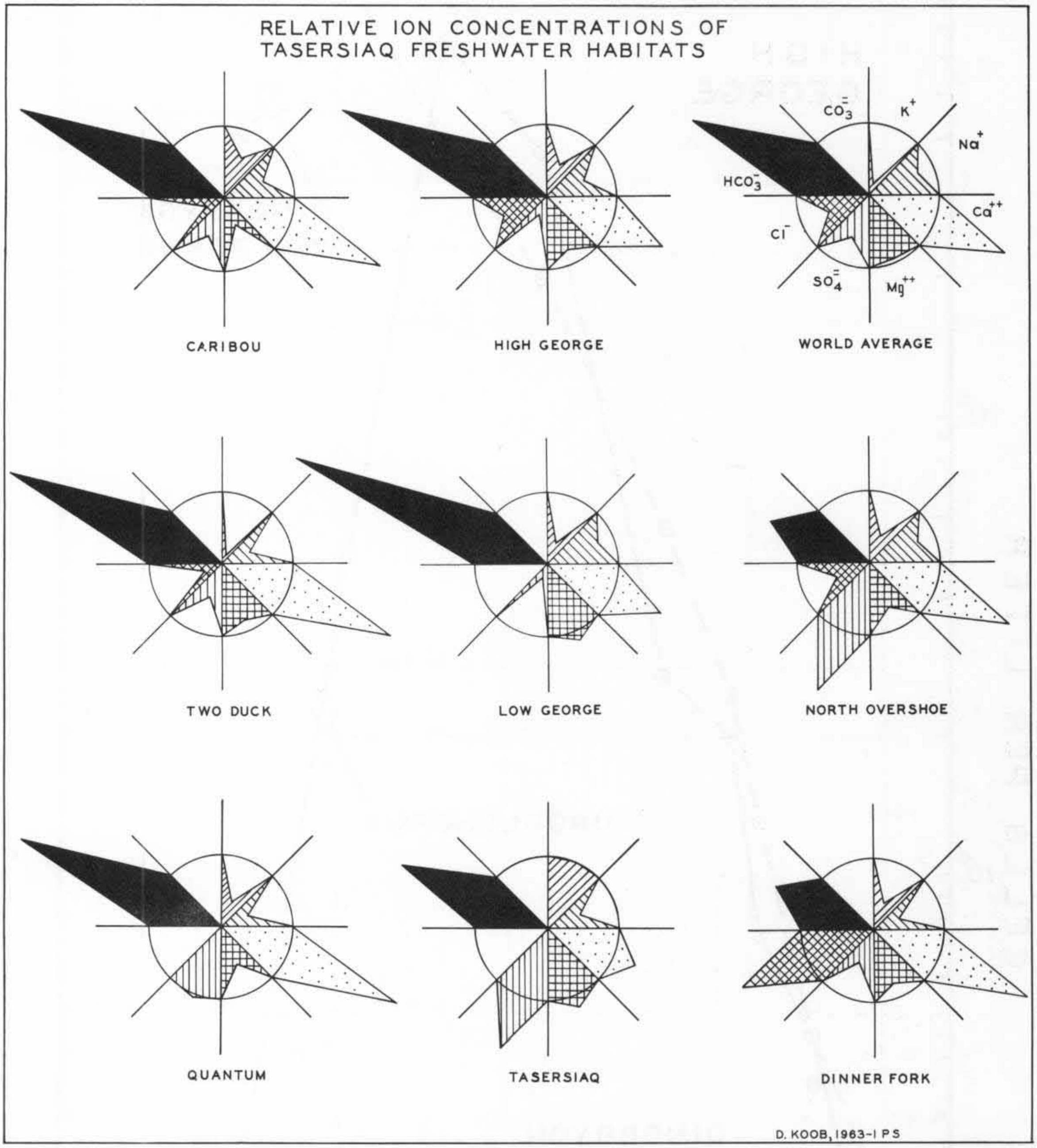

Fig. 3 - Ion Field Diagrams. World average is calculated from the data of Livingstone (1963).

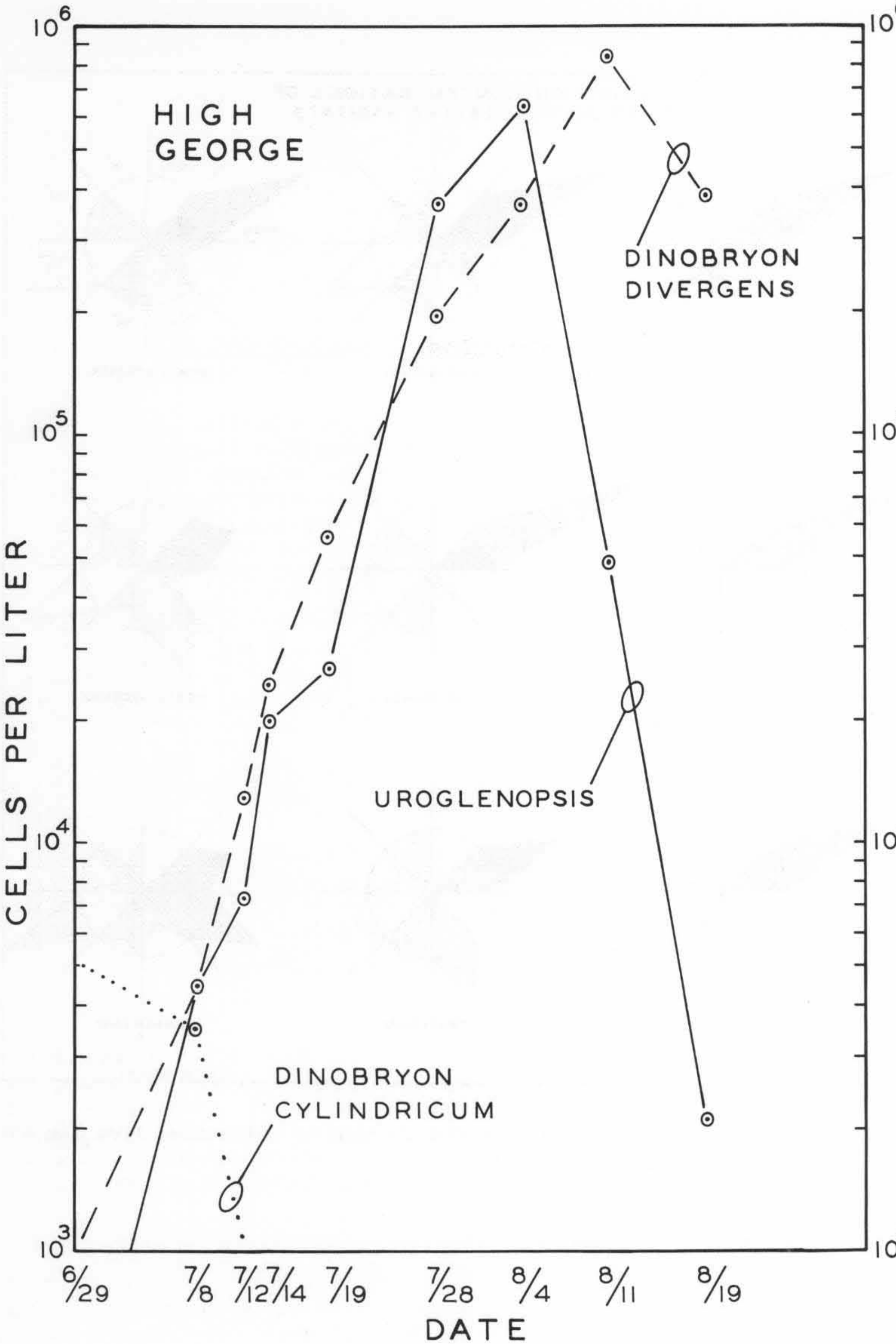

Fig. 4 - Development of the dominant phytoplankton populations in High George Lake.

FAUNA OF THE WESTERN TASERSIAQ AREA, SOUTHWEST GREENLAND

by

PAUL W. RICHARD

INTRODUCTION

From mid-June to mid-August, 1963, observations were made and specimens were collected from the Sukkertoppen-Tasersiaq area of southwest Greenland.

The region contains tundra vegetation and characteristic rock fields. The area is bordered on the east by Lake Tasersiaq with its heavily silted waters, and on the north and west sides by the Sukkertoppen Ice Cap. To the west, Avangnardleq Gorge is blocked by lakes and glacial tongues from the ice caps. On the south, the area is blocked by the Inland Ice and Lake Quantum. The encompassed area will be referred to as the study area (Frontispiece).

The only area open to normal faunistic movements into and out of the study area is a 400 m strip of land between Lake Quantum and Lake Tasersiaq. However, there is geologic evidence indicating that in the recent past water flowed from Lake Tasersiaq into Lake Quantum. At that time, the study area was completely surrounded by ice and water barriers.

MAMMALS

The mammals seen in the Sukkertoppen area included *Rangifer arcticus* (caribou), *Alopex lagopus* (Arctic fox), and *Lepus arcticus* (Arctic hare). Careful examination of the study area produced no evidence of rodent populations, although considering the availability of excellent habitat, rodents would be expected in the region.

Alopex lagopus

Five *A. lagopus* were seen during the summer. Some, however, may have been the same animals seen on different occasions. They were observed eating moss and other vegetation. These observations were confirmed by macroscopic examination of feces which were mainly plant matter. Many fresh sites of *Lagopus mutus* (ptarmigan) kills indicated that *A. lagopus* were hunting actively in the area. Three juvenile *A. lagopus* were seen near the camp during the summer.

Rangifer arcticus

During the summer, *R. arcticus* was the dominant animal seen on the tundra. Population counts were made along the lowlands from the north glacier tongue to the west end of Lake Quantum. Caution was used to avoid counting the same herd twice. All *R. arcticus* were counted, including fawns. Most of the animals seen were along the lake shores and in the lowland areas where the plant families Cariaceae (sedges) and Poaceae (grasses) were most plentiful. The animals spent most of their feeding time in the wet bottomland and on nearby moist hillsides.

R. arcticus counts were made in three areas: north of Base Camp to the glacier tongue, south of Base Camp to the west end of Lake Quantum, and on the east side of Lake Tasersiaq.

The R. arcticus count north of the Base Camp remained fairly constant. More than 15 animals were counted on each of 14 occasions. Once during each month more than 20 animals were seen. The maximum number observed in this area was 25 animals. On the basis of 21 counts, the average number of R. arcticus seen in this area was 20.

From Base Camp south to Lake Quantum, the population was much larger, as was the counting area. The maximum number counted here on July 4, 1963, was 65 animals. At least four times from mid-June to mid-August, more than 45 animals were counted on this route. On the basis of 12 counts, the average number of animals in this area was 40.

Three counts of large herds on the east side of Lake Tasersiaq were made using field glasses. On each occasion, more than 70 animals were observed. This region, because of its size, possibly has a population larger than that observed.

The animals in the area did not appear to move around extensively. The same number of does and fawns in a given area were counted repeatedly. On one occasion, a small herd of animals was seen swimming across Lake Tasersiaq. Because of such movements, the maximum count for each area was not used as a population estimate.

Rangifer arcticus food supply

Examination of Salix (willows) in early spring showed signs of heavy browsing, indicating that they composed a large part of the animals' winter food supply. However, observations indicated willows were not eaten regularly during the summer months, when R. arcticus appeared to shift to eating Cariaceae and Poaceae. On the basis of the number of R. arcticus observed in the area, it appears that these animals are rapidly exceeding their food supply.

Mortality and natality of Rangifer arcticus

Predators were not observed in the area, and there was no evidence that recent Eskimo hunting had been a factor in reducing the population. No R. arcticus were examined that had died of starvation during the winter of 1962-63. One fawn was found which had died within its first month of life. In the steep rocky areas many dead animals were found which appeared to have slipped into rocky crevices or over steep cliffs, killing themselves immediately, or becoming crippled and dying later. Three crippled animals were observed during the summer. Since so many skeletons were found in these areas, it appears that death by accident may be one factor controlling R. arcticus populations. During the darkened winter months, animals may be more prone to such accidents.

Natality appears to be high, but does seen during the summer nearly always had one fawn; it was indeed rare to see a doe without a fawn.

BIRDS

Eleven species of birds were seen. The birds most commonly seen were Plectrophemax nivalis (snow bunting), Passerculus sandwichensis (savannah sparrow), and Calcarius lapponicus (Lapland longspur).

Lagopus mutus

Population counts of the L. mutus (ptarmigan) observed in the study area indicated that approximately 25 adult birds occupied the area. One nest was found that contained a clutch of eight eggs. During late July young birds seen with the female parent averaged nine per brood. From the number of dead L. mutus found, it appears that A. lagopus acts as one controlling factor on the population density.

Water birds

Considering the many lakes in the area, there were few water birds. A population of approximately 15 water birds stayed in the area during the summer. Most of these were found on Lake Quantum and the surrounding smaller lakes. Histrionicus histrionicus (harliquin), Clangula hyemalis (old squaw), and Bucephala albeola (bufflehead) ducks were seen during the summer. No nests of these birds were found, nor were any young birds observed. Other than these Aythyinae (diving ducks), the only other water birds observed were the Erolia alpina (dunlin) and several Labipes lobatus (northern phalaropes).

Terrestrial birds

In addition to the passerine birds, which were not counted, three Corvus corax (ravens) and two Falco rusticolus (gryfalcons) were seen inhabiting the region. Also, a few Anthus spinolitta (water pipits) and Acanthis flammea (redpolls) were observed late in July.

FISH

No evidence of fish was found in the lakes studied. Large populations of the Anostracan Branchinecta paludosa and the Notostracan Lepidurus arcticus were present in some of the lakes, further indicating the absence of fish. The highly silted condition of the water in the Sarfatoq River has probably prohibited fish migration from Søndre Strømfjord into the area.

TERRESTRIAL INVERTEBRATES

In late June the only Arthropods to be found were Bombus hyperboreus (bumblebees), Tipulidae (crane flies), and Arachnids (spiders). Only after mid-July did other Arthropods become abundant.

Most terrestrial invertebrates remained close to the ground during the windy summer. This behavior may be adaptive, resulting from the almost constant strong winds flowing off the glaciers and down the valleys.

Insect collections

Four collection areas 50 m in length were marked off. These areas were swept with a 35 cm insect collecting net at the top of the vegetation. One-meter strokes were taken approximately every meter along a straight-line path. Weekly collections were made from late June to early August. Specific identifications of all Diptera are being made by Drs. T. O. Thatcher, of Colorado State University, and H. H. Ross, of the University of Illinois.

Collection area No. 1 was a flat, wet, meadow tundra area near Base Camp. The vegetation was a complex of sedges and grasses. Only Diptera were found in this area.

DIPTERA

Family Sciomyzidae - marsh flies
1 Sepedon sp.

Family Empidae - dance flies
8 specimens

Family Culicidae - mosquitoes
6 Aedes nigripes (Zetterstedt)

Family Muscidae
61 specimens, several genera represented

Family Dolichopodidae - long-legged flies
7 Dolichopus plumipes (Scopoli)

Family Chironomidae - midges
133 specimens - several genera represented

Collection area No. 2 was a south-facing slope 25% covered with rocks. The vegetation was predominately Poaceae and Ericaceae. The following Arthropoda were collected:

DIPTERA

Family Empidae - dance flies
9 specimens

Family Culicidae - mosquitoes
26 *Aedes nigripes* (Zetterstedt)

Family Tipulidae - crane flies
1 *Tipula sp*.

Family Muscidae
31 specimens, representing several genera

Family Fungivoridae - fungus gnats
2 specimens

Family Dolichopodidae - long-legged flies
4 *Dolichopus plumipes* (Scopoli)
1 *Dolichopus groenlandicus* (Zetterstedt)

Family Chironomidae - non-biting gnats
58 specimens, representing numerous genera

HYMENOPTERA

Family Ichneumonidae
3 specimens

NEUROPTERA

Family Hemerobiidae
2 specimens

Collecting area No. 3 was a rocky north-facing slope with the same general vegetation as area No. 2. The following Arthropoda were collected:

DIPTERA

Family Tipulidae - crane flies
2 *Tipula sp*.

Family Culicidae - mosquitoes
38 *Aedes nigripes* (Zetterstedt)

Family Empidae - dance flies
7 specimens

Family Muscidae
26 specimens, representing several genera

Family Ephydridae - shore flies
2 specimens

Family Chironomidae - non-biting midges
58 specimens - several genera represented

HYMENOPTERA

Family Ichneumonidae
2 specimens

TRICHOPTERA

Family____________________ - caddis flies
2 specimens

LEPIDOPTERA

Family Lycaenidae - butterfly
1 specimen

Collection area No. 4 was a flat, poorly drained area similar to area number one. The following Arthropoda were collected:

DIPTERA

Family Empidae - dance flies
2 specimens

Family Culicidae - mosquitoes
20 *Aedes nigripes* (Zetterstedt)

Family Muscidae
14 specimens, several genera represented

Family Ephydridae - shore flies
3 specimens

Family Chironomidae - midges
36 specimens, representing several genera

HYMENOPTERA

Family Ichneumonidae
1 specimen

HEMIPTERA

Family ____________________
3 specimens

OTHER ARTHROPODS

Other Arthropods were collected throughout the summer of 1963 from areas other than those above.

Insecta

Coleoptera

Dytiscidae (diving beetle)

<u>Colymbetes</u> <u>sculptilis</u>

Coccinellidae (lady bird beetle)

<u>Coccinella</u> <u>transversoguttata</u>

Lepidoptera

Pieridae (cabbage butterflies)

Lycanaeidae (gossamer-winged butterflies)

Arctiidae (tiger moths)

Noctuidae (owlet moths)

Diptera

Trachinidae (trachinid flies)

<u>Phorocera</u> <u>sp</u>.

Calliphoridae

Therevidae (stilleto flies)

Gasterophilidae (bot flies)

<u>Casterophilus</u> <u>haemorrhoidalis</u>

Hymenoptera

Bombidae (bumble bees)

<u>Bombus</u> <u>hyperboreus</u>

Anostraca

Branchinectidae (fairy shrimp)

<u>Branchinecta</u> <u>paludosa</u>

Notostraca

Lepiduridae (tadpole shrimp)

<u>Lepidurus</u> <u>arcticus</u>

Acri

Bdellidae (mites)

<u>Neomolgus</u> <u>littoralis</u>

CONCLUSION

The most striking feature of the fauna in the Sukkertoppen area was the absence of many animal species. A complete absence of fish in all lakes in this region was entirely unexpected. The heavily silted glacial water of the major river may function as a barrier beyond which fish cannot pass. Fish are abundant in the lakes and streams without heavy silt load near Sondrestrom Air Force Base. Few species of birds were found in the study area.

The Sukkertoppen region offers worthwhile areas for more extensive faunistic investigations. Among the vertebrates, comparative studies of rodent populations in adjacent areas would be valuable. The caribou appear to be the major food resource for humans in the area, and studies of the seasonal movement of these animals would be enlightening. The area would be worthy of further investigations particularly among the terrestrial invertebrates.

TAXONOMIC LIST OF TASERSIAQ FAUNA

Chordata
- Mammalia
  - Carnivora
    - Canidae
      - _Alopex lagopus_
  - Lagomorpha
    - Leporidae
      - _Lepus arcticus_
  - Artiodactyla
    - Cervidae
      - _Rangifer arcticus_
- Aves
  - Galliformes
    - Tetranidae
      - _Lagopus mutus_
  - Passeriformes
    - Fringillidae
      - _Plectrophenax nivalis_
      - _Calcarius lapponicus_
      - _Passerculus sandwichensis_
    - Corividae
      - _Corvus corax_
    - Motacillidae
      - _Anthus spinoletta_
  - Falconiformes
    - Falconidae
      - _Falcon rusticolus_
  - Charadriiformes
    - Phalaropodidae
      - _Lobipes lobatus_

Anseriformes
    Anatidae
        Clangula hyemolis
        Histrionicus histrionicus
        Bucephala albeola

Arthropoda
  Insecta
    Diptera
      Scromyzidae
        Sepedon sp.

      Gasterophilidae
        Gasterophilus haemorrhoidalis

      Empidae
      Culididae
        Aedes nigripes

      Therevidae
      Muscidae
      Dolichopodidae
        Dolichopus plumipes
        Dolichopus greenlandicus

      Calliphoridae
      Chironomidae
      Tipulidae
        Tipula sp.

      Fungivoridae
      Ephydridae
      Simuliidae
      Trachinidae
        Phorccara sp.

    Hymenoptera
      Bombidae
        Bombus hyperboreus

      Ichneumonidae

    Lepedoptera
      Lycaenidae
      Pieridae
      Arctiidae
      Noctuidae

    Neuroptera
      Hemerobiidae

Tricoptera
Leptoceridae

Hemiptera
Coleoptera
Dytiscidae
Colymbetes sculptilis

Coccinellidae
Coccinella transversoguttata

Arachnida
Acri
Bdellidae
Neomolgus littoralis

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